AN INTRODUCTION TO ULTRA-HIGH-FREQUENCY CONVERTERS FOR TELEVISION RECIEVERS

BY

W. W. VALLANDIGHAM

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by

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PREFACE

This paper is not intended to prove the superiority of certain configurations over others, but rather to indicate some of the factors to be considered and the methods used in the design of a satisfactory ultra-high-frequency converter.

Investigation of the problems involved was commenced in the fall of 1950 at the U. S. Naval Postgraduate School, and was continued through the winter at the Home Instrument Advanced Development Section of the RCA Victor Division of R.C.A., Camden, New Jersey. This work was done in order to present an overall picture of the ultra-high-frequency converter problems as they exist today, including some background and historical information.

This writer wishes to express his appreciation to Dr. W. Y. Pan, T. Murakami, and W. R. Koch of the RCA Victor Division of the Radio Corporation of America for their valuable assistance in collection of pertinent information and material.

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TABLE OF SYMBOLS AND ABBREVIATION

e_1	Equivalent mixer efficiency in responding to the direct f_i interfering signal
e_2	Equivalent mixer efficiency in responding to the $\frac{1}{2}$ f_i interfering signal
e_3	Equivalent mixer efficiency in responding to the 1/3 f_i interfering signal
e_{m1}	Equivalent mixer efficiency in responding to i-f and image signals resulting from the local oscillator signal and the interfering signal
e_{m2}	Equivalent mixer efficiency in responding to $\frac{1}{2}$ i-f and $\frac{1}{2}$ image interfering signals
e_{m3}	Equivalent mixer efficiency in responding to 1/3 i-f and 1/3 image interfering signals
e_{my}	Equivalent mixer efficiency in responding to 1/y i-f and 1/y image interference signals
e_n	Equivalent mixer efficiency in responding to the desired signal
e_{ox}	Equivalent mixer efficiency in responding to an interfering signal formed in conjuction with the xth harmonic of the local oscillator
e_{oxmy}	Equivalent mixer efficiency in responding to an interference signal formed by the yth harmonic of the mixer in conjunction with the xth harmonics of the local oscillator
f_i	Intermediate frequency of u-h-f converter or receiver
G	Gain of the stage
G_k	Ratio of the voltage across the final load R_2 to the equivalent generator voltage
N_1	Effective step-up of the input circuit
N_2	Effective step-up of the output circuit
R_1	Equivalent signal generator resistance
R_2	Final load (input loading of next stage)
$R_{eq.}$	Equivalent tube noise resistance

R_L Resistance seem looking forward from output terminals of the tube R_2/N_2^2

Ro Output impedance at plate of the tube

R_p Effective plate resistance of the tube

Z_{in} Input impedance of the tube

CHAPTER I

INTRODUCTION

1. Summary

The rapid growth of electronics engineering in the past few years has produced many new fields of interest for the average engineer. The development has been so rapid, however, that it is no longer possible for the individual to keep up with its tremendous growth. It is necessary, therefore, that from time to time material concerning a particular phase of electronics be collected and presented in an organized manner as a ready reference. Such a task has been undertaken by the writer in this presentation on u-h-f converters.

It would be impossible to cover in detail all of the aspects concerning this work. An attempt is made, however, to acquaint the reader with an overall picture of this field and to bring him up to date on the major design problems and considerations for commercial u-h-f converters. Some design data is included for those who desire to continue further in this work.

2. What, why, where, when, and how

In considering the design of a u-h-f converter one must answer first several basic and fundamental questions. What is a u-h-f converter, why is it necessary, where does it fit into the present day television field, when will it become important, and how does it differ from a u-h-f tuner?

A u-h-f converter is an adaptor which when used with the existing v-h-f receiver enables the user to select a desired u-h-f program. Recent proposals by the F. C. C. indicate that 65 to 70 additional television channels will be allocated in the frequency range from 470 to 890 Mc. Since the majority of the present day television receivers are designed to cover only the range from 54 to 216 Mc, some means must be provided to convert these receivers to u-h-f reception. Hearings on the new proposals are to commence during May of 1951, and it is anticipated that transmission of u-h-f will commence sometime in 1952, or possibly early 1953. It is important, therefore, that u-h-f techniques be brought to the stage of development where it is practical to manufacture converters in quantity for general public use. Unfortunately, until recent years, little work has been done in this frequency range leaving many problems to be solved in a relatively short period of time.

The u-h-f converter, unlike the v-h-f tuner, must operate in a region where lumped constant circuits are impractical yet distributed constant circuits are not desirable. For example, the self inductance of a length of #22 straight round wire 1 inch in length is approximately .02 uhys, yet a quarter wave length at 500 Mc is 5.9 inches. Oscillator frequency drift must be held to a much closer percentage tolerance. Noise factor is of primary importance due to reduced propagation character-

istics. Spurious and image responses are also of more importance at u-h-f than at v-h-f.

3. Factors for design consideration

The design engineer is faced with many factors when undertaking the development of a practical u-h-f converter. No one factor can be separated from the next. At best, the final completed product is the result of a series of compromises. Cost is of major importance if the converter is to be sold commercially. Space, weight, and mechanical ruggedness is of importance in all cases. The type of service, such as (1) experimental, (2) military, or (3) commercial, determines many features in the design. The method of tuning or station selection must be given close attention, as well as many other problems of similar nature. Of prime importance, also, are performance considerations which cover such factors as (1) freedom from spurious responses (2) noise factor (3) oscillator radiation (4) oscillator stability, etc. Each of these problems will be given further consideration in more complete detail in chapter III.

4. Basic design

In general, the basic design of a u-h-f converter is not too different from that of a conventional superheterodyne circuit. Its general composition is as follows:

1. Signal frequency circuits - r-f amplifier tube or tuned circuits.
2. Oscillator frequency circuits and oscillator tube.

3. Frequency changing tube or crystal.

4. Low noise intermediate frequency stage.

5. Balance to unbalance device.

6. Traps and filters.

The circuitry and tubes used to accomplish the desired results in each stage are not, however, of the conventional type. It would be difficult in many cases for the ordinary observer to identify the various components.

5. F. C. C. proposals

To intelligently develop and build a converter for commercial use one must study closely, proposals as put forth by the F.C.C. in it's "Third Notice of Future Proposed Rule Making" of March 1951 (7), as well as previous notices by this same commission. Of interest, also, are the reports to the Commission by the Ad Hoc Committee (19), which it established to study propagation effects at ultra-high-frequencies.

To date, major points of the proposals are as follows:

No. of channels	Assignments Frequency range	Channel No.	Type Service
12	54-216 Mc	2 thru 13	Commercial or non-commercial and educational television
52	470-782 Mc or 500-812 Mc	14 thru 65	
13 or 18	782 or 812-890 Mc	66 thru 78 or 83	Flexibility channels

The frequency band from 470-500 Mc is under consideration for assignment to multichannel, broad-band, common-carrier,

mobile radio service. If this assignment is not made u-h-f television broadcast will commence at 470 Mc, otherwise at 500 Mc.

The required median field strengths in db above 1 uv/m listed below given some idea of expected service grades.

*Grade Service	Channel 2-6	Channel 7-13	Channel 14-83
A	68 db	71 db	74 db
B	47 db	56 db	64 db

Some idea of necessary discrimination against spurious responses may be obtained from the following co-channel and adjacent channel interference ratios. Permissible co-channel ratios are in db of median desired field strengths to 10% undesired field strength.

	Channel 2-13		Channel 14-83	
Grade Service	No offset	Offset	No offset	Offset
A	51 db	34 db	53 db	36 db
B	45 db	28 db	45 db	28 db

Because of improvements which can result from a small shift of carrier frequency of co-channel stations, the F.C.C. will authorize a fixed carrier offset of ± 10 KC from the assigned channel frequency. By this means, co-channel minimum required separations have been reduced from 200 miles (for u-h-f) to 165 miles.

Permissible adjacent channel ratios in db of median desired field strengths to undesired field strengths.

*Grade A - metropolitan area Grade B - rural area

Grade Service	Channel 2-83
A	o db
B	o db

Transmission standards for all channels will be those which are set forth in "Standard of Good Engineering Practice Concerning Television Broadcast Stations" by the Federal Communications Commission.

CHAPTER II

EARLY DEVELOPMENT IN U-H-F

1. General

It is interesting as well as instructive to review the development of u-h-f in the past few years. Some work was accomplished in this field during the war years. However, the major contributions to actual television converter design for u-h-f has been accomplished since that period. During September 1944, the F.C.C. held public hearings with the purpose of reviewing existing allocations in the light of future needs. As a result of these hearings and other developments, commercial television was assigned 12 channels in the v-h-f region. There was insufficient information in the u-h-f region to set standards and allocate frequencies at that time. It was necessary to determine if v-h-f standards could be adapted to u-h-f with respect to service areas, practical radiated powers, antenna height, station separation, etc.

2. Propagation test results

In the summer of 1946 simultaneous field strength recordings of radio transmission of 47.1 Mc, 106.5 Mc, and 700 Mc from New York to Princeton were made (4). Results of these recordings revealed a trend towards higher field strengths at higher frequencies when the standard atmosphere was disturbed, i.e. when the dielectric gradient of the medium was abnormal. Field strengths as large as eight times normal were recorded occasionally on

700 Mc at the receiving location during rain storms.

Concurrent with the Princeton investigation, a study of propagation and multipath effects under typical broadcast conditions was undertaken by another group from RCA (3). Comparative measurements were made at 67.25 Mc, 288 Mc, 510 Mc, and 910 Mc along two radial directions from the antennas located atop the Empire State Building in New York City. Best agreement with theoretical values at all frequencies was obtained along the southwest radial over comparatively smooth ground. Shadowing from hills and other obstructions increased steadily as frequency increased. At 510 Mc and 910 Mc multipath effects were quite severe. Results indicated probable need for rotatable directive antennas. However, this will not completely solve the problem. In general, the service area depicted by series of contour curves of constant field intensities will be about the same size for high frequency as for low frequency, but service area for high frequency will be spotted with local areas where signal is non-existent or low.

Further tests conducted in the Washington, D. C. area (2) were within reasonable agreement with those of previous transmission tests. One of the major difficulties in the Washington tests was to locate a spot where the main signal was strong enough for reception.

The first experimental u-h-f station KC2XAK Bridgeport, Connecticut (8) was authorized by the F.C.C. on May 4, 1949.

Construction of this installation was completed on November 15, 1949, and transmission of a 6 Mc television signal on 529-535 Mc was commenced shortly afterwards. The station operated as a satellite of WNBJ (Channel 4), New York with a peak visual signal of 1 kw and an aural signal of 1/2 kw into a 210 foot antenna having a gain of 17 db and an overall system efficiency of 80%. Results of tests at Bridgeport to date have indicated that good pictures may be received over 15 miles from the transmitter, but that fair or even poor pictures may be received at some installations only five miles away. This is considerably under the line of sight transmission range as can be seen from figure 1 even though only the transmitting antenna height is used to compute distance. In general, a field intensity of 10,000 uv/m from a 1/2 λ dipole will give excellent picture quality and 1,000 uv/m a fair but noisy picture. Picture quality is not determined solely by air distance between receiver and transmitter because of difference in terrain condition, type of receiver antennas, elevations, antenna height, and length of transmission lines.

3. F.C.C. proposals

July 1949 saw the delivery of proposals for new stations by the F.C.C. for 42 additional 6 Mc channels in the u-h-f band. Grades of service were to be classified as A-metropolitan, B-urban, C-rural. Permissible co-channel interference ratio and required median field intensity were quite similar to the present proposals.

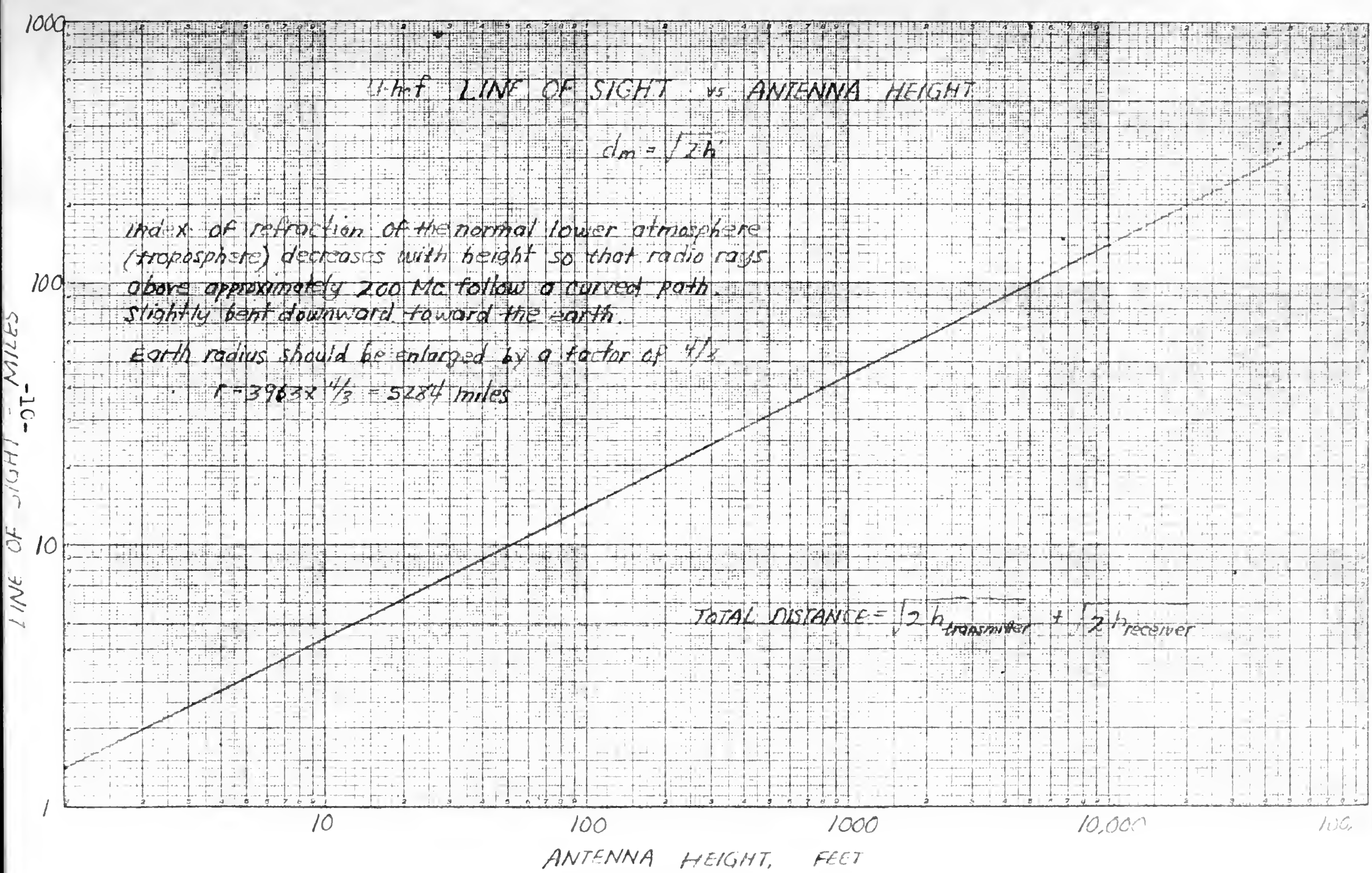

U-h-f LINE OF SIGHT vs ANTENNA HEIGHT
$d_m = \sqrt{2h}$
index of refraction of the normal lower atmosphere (troposphere) decreases with height so that radio rays above approximately 200 Mc follow a curved path, slightly bent downward toward the earth.
Earth radius should be enlarged by a factor of 4/3
$r = 3963 \times 4/3 = 5284$ miles
TOTAL DISTANCE = $\sqrt{2h_{transmitter}} + \sqrt{2h_{receiver}}$
1000
100
10
1
10
100
1000
10,000
LINE OF SIGHT - MILES
ANTENNA HEIGHT, FEET

Figure 1

The permissible adjacent channel ratios were considerably higher.

4. Early type converter

One of the first type of u-h-f converters to be constructed was one developed by RCA for reception of the Washington, D. C. test transmissions during the fall of 1948 on 504 Mc to 510 Mc. This converter tuned only from 500 Mc to 600 Mc. A similar converter (16) was built by RCA for use in field tests of the experimental station KC2XAC at Bridgeport. This converter used a modified transmission line tuning system in a double heterodyne principle to convert the range from 500-700 Mc to 21-27 Mc. This signal was fed into the front end of a conventional television receiver. Noise factor ranged from 14-18 db, oscillator radiation from 60-450 uv/m at 100 feet. Oscillator drift was 150 kc in the first 1/2 minute with preheated heaters.

Operational characteristics of some other early types of converter were:

Harnett - General Electric		Three tuned lines-sliding contracts
Oscillator radiation	400 Mc	500 uv/m at 100 ft.
	800 Mc	2600 uv/m at 100 ft.
Oscillator drift	400 Mc	1.75 Mc
	800 Mc	4.25 Mc two minutes after switch "on", stabilized in thirty minutes.

John Bell-Zenith   Turret type - fixed tuned strips

Noise factor	early design	25-28 db	
	recent design	20 db	
Image ratio		30-50 db	
Oscillator radiation	91 Mc fundamental		- .442 uw
	6 th harmonic (used)		- .0024 uw
	107 Mc fundamental		- 3.21 uw across antenna terminals only
Tuned Circuit Q	500-600		
Transmission Line Loss	Amphenol 300 ohm tubular line		.6 db/50' dry
			1.6 db/50' wet
			2.7 db/50' wet ground

Bussard - Crosley Converter i-f 130 Mc

Oscillator radiation	450 Mc - Oscillator frequency	7.1 uw	1.85 uw (with shielding)
	500 Mc	.46 uw	.51 uw "
	550 Mc	1.47 uw	6.55 uw "
	600 Mc	--	.235 uw "
Oscillator Drift	350 Mc - oscillator frequency		-600 kc
	450 Mc		-800 kc
	610 Mc		1400 kc

Van Dyke - Dumont

Converted to channel 3

Noise factor   20 db

Dumont tuner - Double conversion superheterodyne

First i-f	135 Mc	Second i-f	41.25 Mc
Image ratio	49 db at 500 Mc		34 db at 80 Mc
Second harmonic image	34 db		
I-f rejection	>70 db		> 60 db
Radiation (520 ohm)	14,000 uv		70,000 uv
	3.8 uw		94 uw

Dumont tuner- Single conversion (continuous tuning)

I-f	41.25 Mc	
Image ratio	20 db at 500 Mc	6 db at 800 Mc
Radiation	15,000 uv	40,000 uv
Oscillator drift	430 kc/20° C rise	

One of the more recent u-h-f converters developed by RCA which could be considered as a finished commercial design for the 500-700 Mc range is the Model P (17). As may be seen from the circuit design, figure 2, this converter employs a crystal mixer followed by a low noise i-f amplifier. Characteristics are as follows:

Oscillator radiation field intensity at 100 feet from a ½ λ dipole

600 Mc	700 Mc
Less than 20 uv/m	less than 50 uv/m

Oscillator stability-maximum of 100 kc drift

Noise factor - 13 db

FIG.2

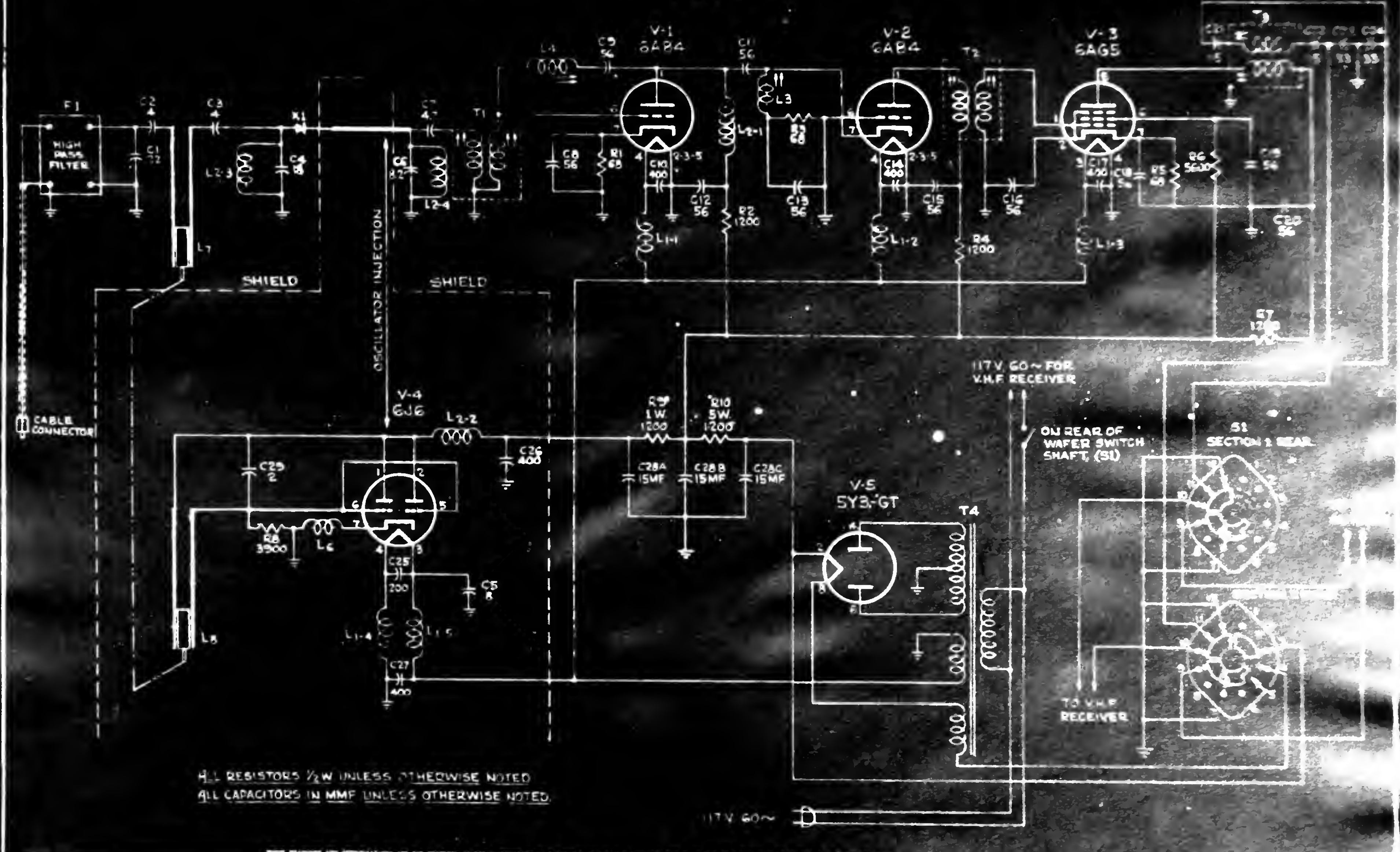


FIGURE 2

U.H.F. CONVERTER

TYPE P

RADIO CORPORATION OF AMERICA
RCA VICTOR DIVISION

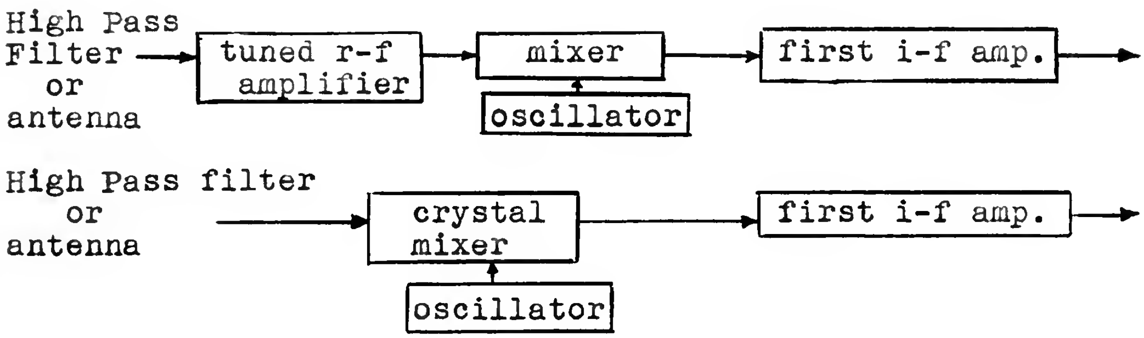
C971218

CHAPTER III

MAJOR PERFORMANCE DESIGN CONSIDERATIONS FOR COMMERCIAL U-H-F CONVERTERS

1. Basic circuits

Choice of the basic converter design is divided, generally, into two classes. One employs an r-f amplifier followed by a mixer (crystal or tube)-oscillator stage, then to the first i-f amplifier. The other has no r-f amplifier, but feeds the signal directly to a crystal mixer-oscillator stage, then to the first i-f amplifier. The two types are outlined in the block diagram below.



Both systems operate on a double superheterodyne principle using one of the v-h-f channels as the converter intermediate frequency.

Calculated performance data for various types of grounded grid i-f amplifiers from an unpublished report by R. F. Romero is shown in figure 3. The pencil triode used is the 5675 (RCA). R_a is the transformed antenna resistance which is reflected to the r-f amplifier cathode.

R-F TUBE	MIXER	R_A - OHMS	NOISE FACTOR db	VOLTAGE GAIN	LOCAL OSC. POWER REQ'D. MICROWATTS	LOCAL OSC. RADIATION MICROWATTS
PENCIL TRIODE	CRYSTAL & 6 db I-F AMPL. N.F.	1 119	10.4	$3.44\sqrt{R}$	500	$0.117\ A^2$
PENCIL TRIODE	CRYSTAL & 3 db I-F AMPL. N.F.	1 153	9.3	$3.18\sqrt{R}$	500	$0.128\ A^2$
PENCIL TRIODE	PENCIL TRIODE	2 300	9.5	$3.77\sqrt{R}$	8100	$11\ A^2$
6J4	6J4	3 65	12.4	$7.56\sqrt{R}$	45,000	$120\ A^2$

1 FOR MIN. NOISE FACTOR AND MIXER R-F IMPEDANCE TRANSFORMED TO 10,000 OHMS AT R-F AMPL. PLATE.

2 FOR ANTENNA MATCH AND MIXER R-F IMPEDANCE TRANSFORMED TO 10,000 OHMS AT R-F AMPL. PLATE.

3 FOR ANTENNA MATCH AND MIXER R-F IMPEDANCE TRANSFORMED TO 5,000 OHMS AT R-F AMPL. PLATE.

NOTE: NOISE FACTOR VARIES VERY SLOWLY AS R_A IS VARIED.

CALCULATED PERFORMANCE DATA AT 600 MC.

Figure 3

In two cases, R_a was chosen to minimize the noise factor. In the other two cases, R_a was chosen for a match. Factor A in the table is the ratio of oscillator voltage appearing at the r-f amplifier plate to that at the mixer. This factor depends on selectivity of interstage tuned circuits and the amount of direct coupling from the oscillator to the r-f amplifier plate.

Theoretical noise factor curves for grounded grid amplifier stages using the 2C40 (similar in performance to 6F4), the 5876 (pencil triode), and the Western Electric 416 A (triode), as well as the beam deflection mixer and the crystal mixer receiver, are plotted in figure 4. Crystal type converters, as can be seen from the curves, are characterized by the fact that noise factor is practically constant over the entire range, determined primarily by the intermediate frequency.

For commercial design purpose, the crystal type of converter is probably to be preferred over the amplifier due to lower cost and greater simplicity. With the exception of the pencil triode, the tubes mentioned above are considerably more expensive than available crystal mixers.

2. Oscillator characteristics

Oscillator characteristics determine, to a large extent, the success or failure of a u-h-f converter design. Of primary importance is the problem of oscillator radiation, both direct and through the antenna. A suggested limit for maximum radiated field strength at

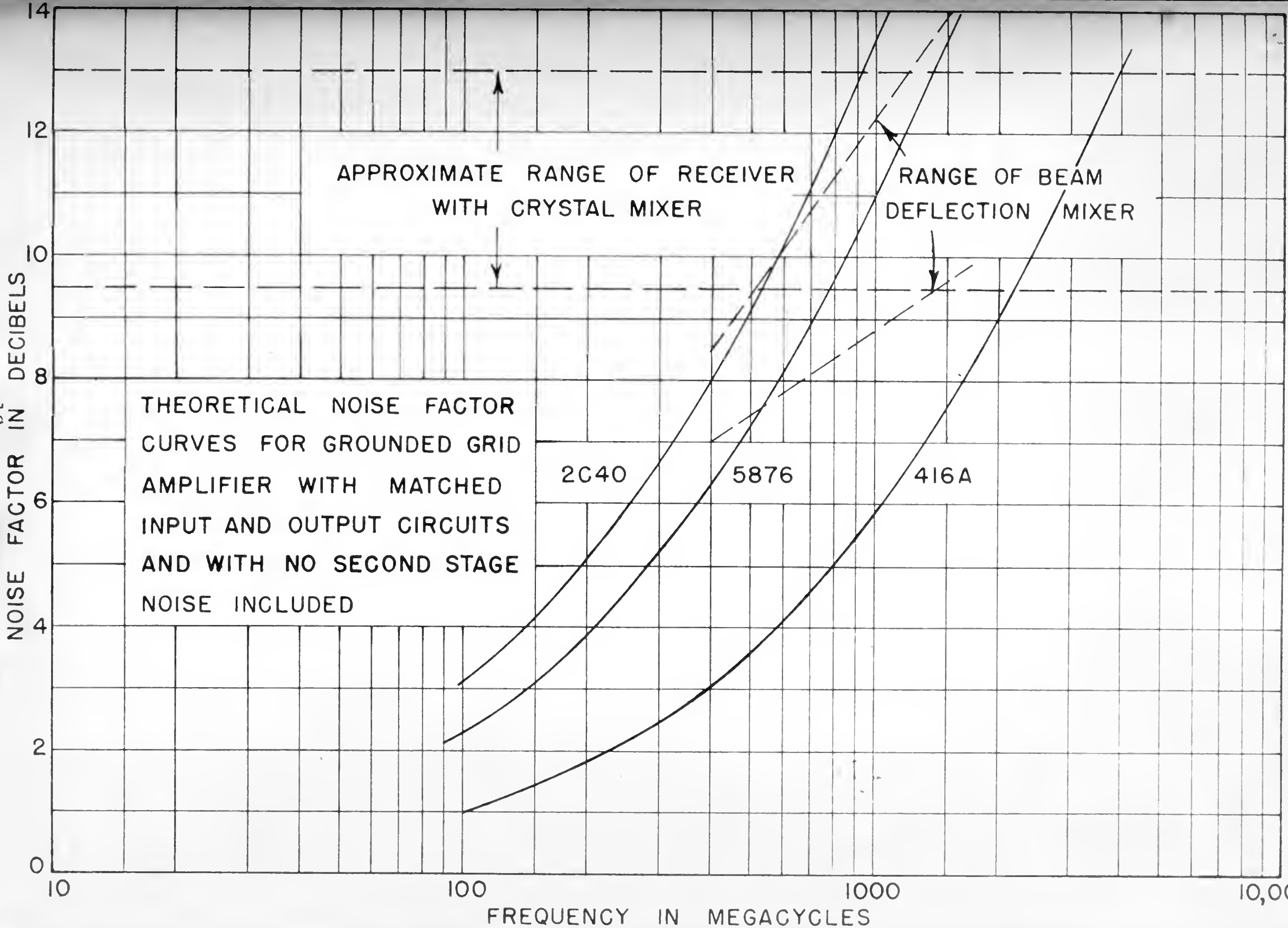

14
12
10
8
6
4
2
0
NOISE FACTOR IN DECIBELS
APPROXIMATE RANGE OF RECEIVER
WITH CRYSTAL MIXER
RANGE OF BEAM
DEFLECTION MIXER
THEORETICAL NOISE FACTOR
CURVES FOR GROUNDED GRID
AMPLIFIER WITH MATCHED
INPUT AND OUTPUT CIRCUITS
AND WITH NO SECOND STAGE
NOISE INCLUDED
2C40
5876
416A
10
100
1000
10,000
FREQUENCY IN MEGACYCLES

Figure 4

100 feet is 15 microvolts per meter. From figure 17 it may be seen that this corresponds to a radiated power of .004 microwatts. The problem of direct chassis radiation is a function of oscillator shielding, chassis dimensions, (cavity resonances), etc., and reduces to one of confining all oscillator energy to the tuner enclosure. Precautions which may be observed to minimize oscillator radiation are:

1. All power leads to the converter by-passed.
2. Shield cans placed around the oscillator tube.
3. I-f output lead kept free of oscillator voltage.
4. RC filter in oscillator plate supply.
5. LC filter isolating converter heaters.
6. Proper selection of ground on the converter unit and in the chassis for both the oscillator and r-f sections.
7. Input to r-f stage shielded.
8. Ground turret shaft in case of turret type tuning.
9. Shielding of r-f circuits from oscillator.

The use of a crystal mixer reduces the problem of oscillator radiation since excitation power required is only 400 to 500 microwatts. Raising the intermediate frequency or reducing bandwidth is another method, since the radiated power through a converter antenna is directly proportional to the square of the r-f bandwidth and inversely proportioned to the square of the intermediate

frequency. Note: (see appendix A). Use of an r-f amplifier head of the mixer may not be of much help since oscillator radiation from the antenna is a function of the capacitance from the r-f amplifier output terminal to the antenna terminal and circuit impedance at these terminals. Capacitances across the tube will vary usually from 1 to 2 uuf. In order to achieve a .004 microwatt radiated power level, the attenuation from the crystal to the antenna must be more than 100 db.

Stability of the oscillator is another large problem. To prevent the necessity of frequent retuning, drift in the converter must be held to 50 kc to 100 kc. If intercarrier sound is used these limits may be raised to 150 kc to 200 kc. Drift may be divided into two classes; (1) short time (up to 15 minutes after power is turned on) and (2) long time.

Short time drift is due to heat conducted through base pins to the tube socket contacts, the change being related closely to the tube elements. A small valued capacitor with negative temperature coefficient may be connected across two appropriate socket terminals so as to vary with temperature rise. Leads should be kept as short as possible, and more heat will be received if one terminal is connected to one of the heater terminals. Adding this capacitor across part of the tank circuit will allow a larger value of capacitance to be used. The correct value of this capacitor may be calculated by determination of frequency drift in terms of change in effective tank

capacitance.

Another type of compensation which has been used is a special tube shield which expands with heat, lowering plate to grid capacitance. Tests on tube sockets have revealed, also, that rubber filled mica sockets are 50% better than phenolic type sockets.

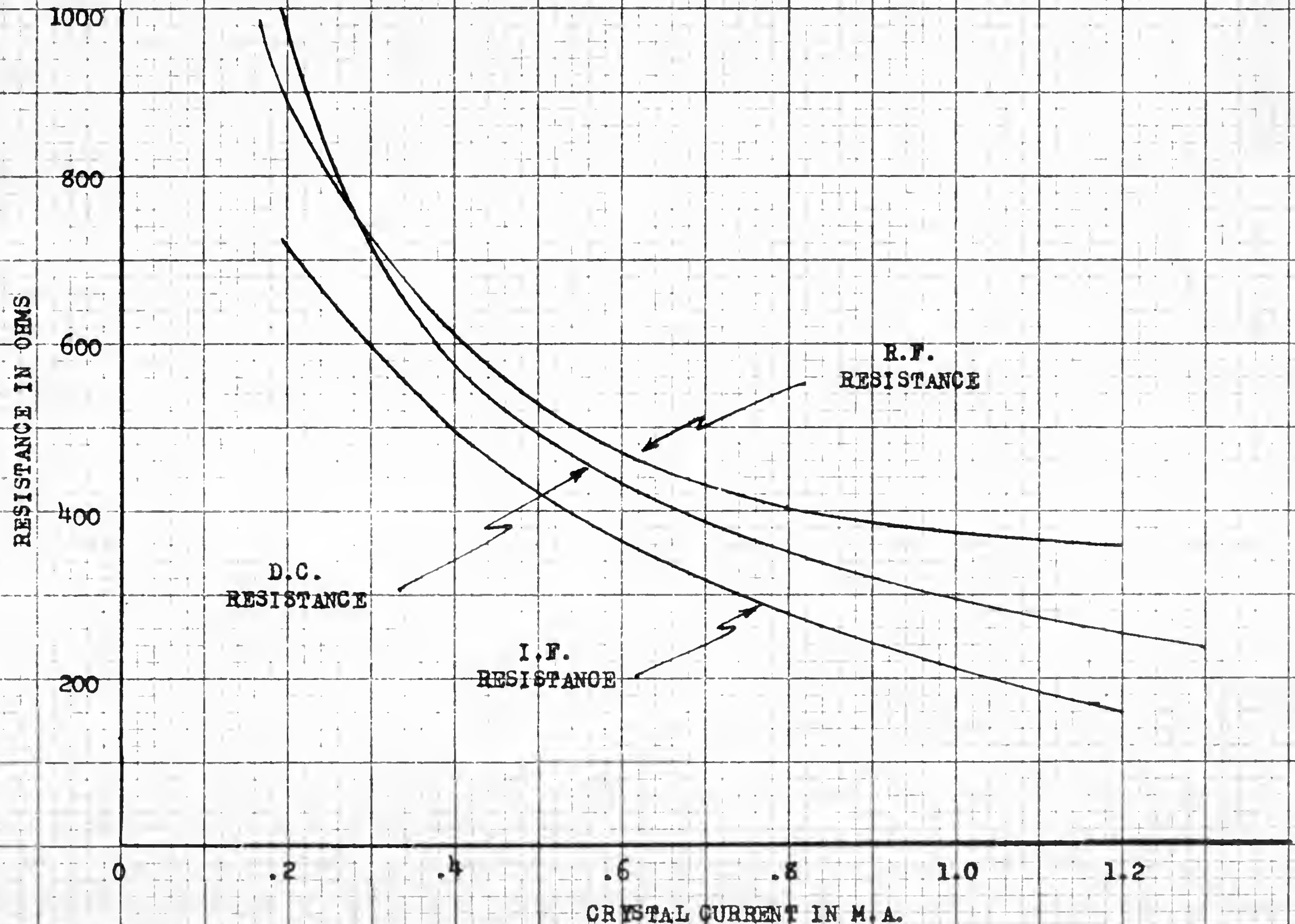
Long time drift is due to change in the remainder of oscillator circuits. These changes may be compensated for by proper coil and condenser design.

One of the main difficulties experienced in oscillator circuits has been tube replacement. Discrepencies in drift (more than $\pm$ 50 kc) between tubes require special compensation for each particular converter. Thus each change of a tube requires new compensation. Work is being done by the manufacturer to hold tube variations within reasonable limits.

Another source of stability difficulty is variation of line voltage and supply voltage. Automatic frequency control (AFC) is not the solution since commercially it is costly.

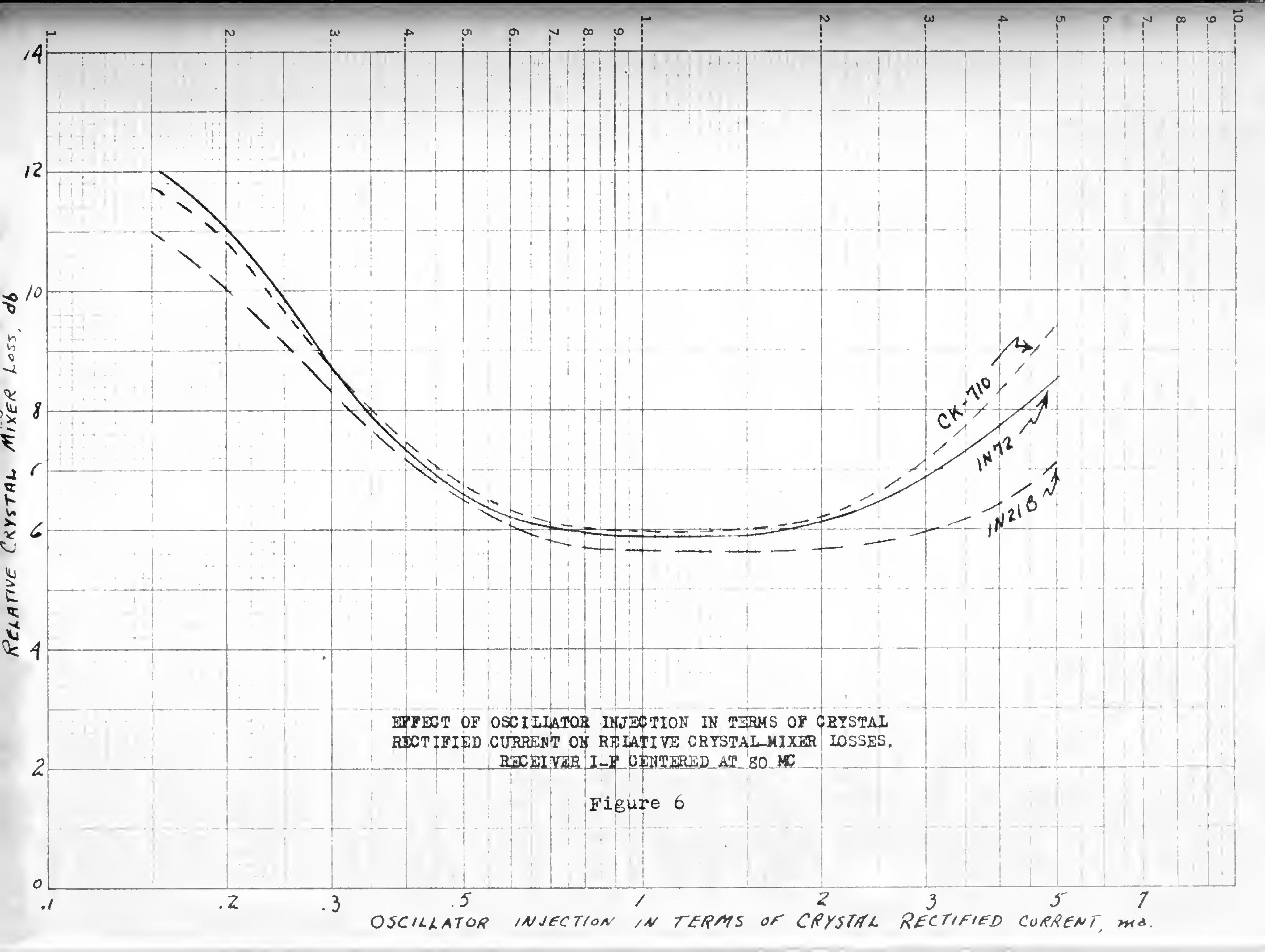
Other factors entering into the oscillator design characteristics are hum frequency modulation, microphonics, and such mechanical problems as reset accuracy and fine tuning adjustment. Solution to these problems is, primarily, careful design.

Injection is of primary importance especially in crystal mixers as can be seen in figures 5 and 6. Mixer



THE VARIATIONS OF R-F, I-F AND D-C RESISTANCE OF A TYPICAL G-7 CRYSTAL RECTIFIER WITH OSCILLATOR INJECTION

Figure 5



EFFECT OF OSCILLATOR INJECTION IN TERMS OF CRYSTAL
RECTIFIED CURRENT ON RELATIVE CRYSTAL MIXER LOSSES.
RECEIVER I-F CENTERED AT 80 MC

Figure 6

loss is increased outside a certain optimum operating range, and crystal impedances to r-f and i-f vary widely with variations in rectified crystal current. Some means, therefore must be provided to maintain constant oscillator injection to the mixer.

3. Interference reduction (freedom from spurious responses)

Interference reduction at u-h-f is one of the most difficult and, at the present time, probably the furthest from a satisfactory solution.

Interference may be divided into three types.

1. Inherent random-noise voltage, generated in the receiver.

   a. thermal agitation

   b. shot effect

   c. impulse-noise voltage induced in the antenna.

Noise of this type is characterized by a uniform distribution of energy over the frequency band being used. It is independent of selectivity.

2. Low frequency voltages, usually originating in the receiver.

   a. hum or ripple from power supply, etc.

   This type may be eliminated by proper construction.

3. Unwanted carriers, modulated or unmodulated at r-f.

These types of interferences produce easily recognized patterns on the television picture. Frequency modulation produces the familiar herring-bone pattern. A stable carrier, amplitude modulated or unmodulated may superimpose spots or cross-bars. This type of interference

depends entirely on receiver selectivity.

Spurious responses of the third class may be introduced by a signal of intermediate frequency, by a single signal whose frequency bears a definite relationship with the frequency of the local oscillator, or by two signals whose frequencies differ by an amount which bears another definite relationship with the intermediate frequency.

In our new electronic age, the air is filled with many sources of interference such as amplitude and frequency modulated carriers, both amateur and commercial, diathermy radiation, radar, local oscillator radiation from nearby television receivers, etc. Such signals can be of considerable importance, even though they are of low power, if they are located near the converter. Fortunately, such signals are characterized by the fact that they are of the single average frequency type, i.e. modulated carrier, etc. With the exception of response to intermediate frequency signals, and to two interfering signals whose frequency differs by the intermediate frequency, most signals are formed by the presence of a single frequency, interference signal and the local oscillator signal.

During the winter term at RCA, this writer was engaged in a project with Dr. W. Y. Pan and Mr. W. Wittenburg in the investigation of the relative magnitude of various spurious responses of u-h-f television receivers. These responses were divided into several catagories: those formed by the generation of harmonics in the rectifier

during the process of rectification, those formed by the harmonics of the local oscillator, those formed by the presence of a single interfering signal in addition to the local oscillator, and finally those formed by the presence of two interfering signals in addition to the local oscillator. In those tests, a crystal rectifier was used as the mixer stage of the u-h-f test tuner, (similar to figure 22) because a crystal mixer has been preferred, chiefly for economic reasons, in television receivers which are to cover frequencies as high as 890 Mc.

The conclusions reached as a result of this study were as follows:

The spurious responses are formed principally by the generation of harmonics in the local oscillator and the generation of harmonics in the mixer during the process of mixing. For television receivers employing crystal rectifiers as mixers, only the second, third, and possibly the fourth harmonics give rise to interference if the interference is caused by a single interfering signal. Higher order harmonics usually form interference with negligibly low magnitudes.

The effect on television reception of spurious responses formed by the mixer second harmonic is proportional to the square of the strength of the interfering signal, and of those formed by the nth harmonic of the mixer is proportional to the nth power of the strength of the interfering signal. The harmonics generated in the local oscillator form spurious responses which exhibit

entirely different characteristics.

Interference of the two interfering-signal type was also investigated, in which case only the mixer second harmonic introduces disturbance to u-h-f television receivers. In both the single interfering-signal type and the two interfering-signal type, the germanium u-h-f crystal rectifiers seem to be less susceptible to spurious responses compared with the silicon u-h-f crystal rectifiers.

The relative magnitudes of the spurious responses are presented in Chapter IV, Section 5, so that the proper selectivity characteristics of u-h-f receivers and converters may be determined.

4. Noise factor

One important measure of converter performance is noise factor. Considerable work has been done in this field, and there is a wealth of information available in the literature for those interested. (see references in the bibliography) This writer will not attempt to present more than a few factors which are of particular interest in the field of ultra-high-frequency.

Need for a low noise factor indicates the use of a triode which has the following characteristics: high transconductance, low input loading, low input and output capacitances, and a low value of lead inductance. An investigation of the various type triode circuits has indicated the grounded grid circuit as the most satisfactory.

As was pointed out previously, the r-f stage must have sufficient gain to warrant its use. This can be readily shown from the familiar equation

$$F_{12} = F_1 + \frac{F_2 - 1}{G_1}$$

Where

F_{12} = Noise factor of entire amplifier

F_1 = Noise factor of the first stage

F_2 = Noise factor of the remainder of the receiver with source resistance equal to output resistance of the first stage

G_1 = Gain of the first stage

Converter noise in those crystal mixer receivers without an r-f amplifier is principally determined by the intermediate frequency. The optimum range for the intermediate frequency from the standpoint of noise factor is the range from 40 to 50 Mc. The lowest possible i-f in a practical converter is 54 to 60 megacycles (channel 2). At higher intermediate frequencies, converter noise factor is increased due to the characteristics of the i-f tubes. In the lower range increased temperature noise of the crystal raises converter noise factor. Figure 7 shows the theoretical converter noise figure assuming an 6.5 db mixer loss for the average u-h-f mixer crystal. Combined noise factor is determined by the following relationship:

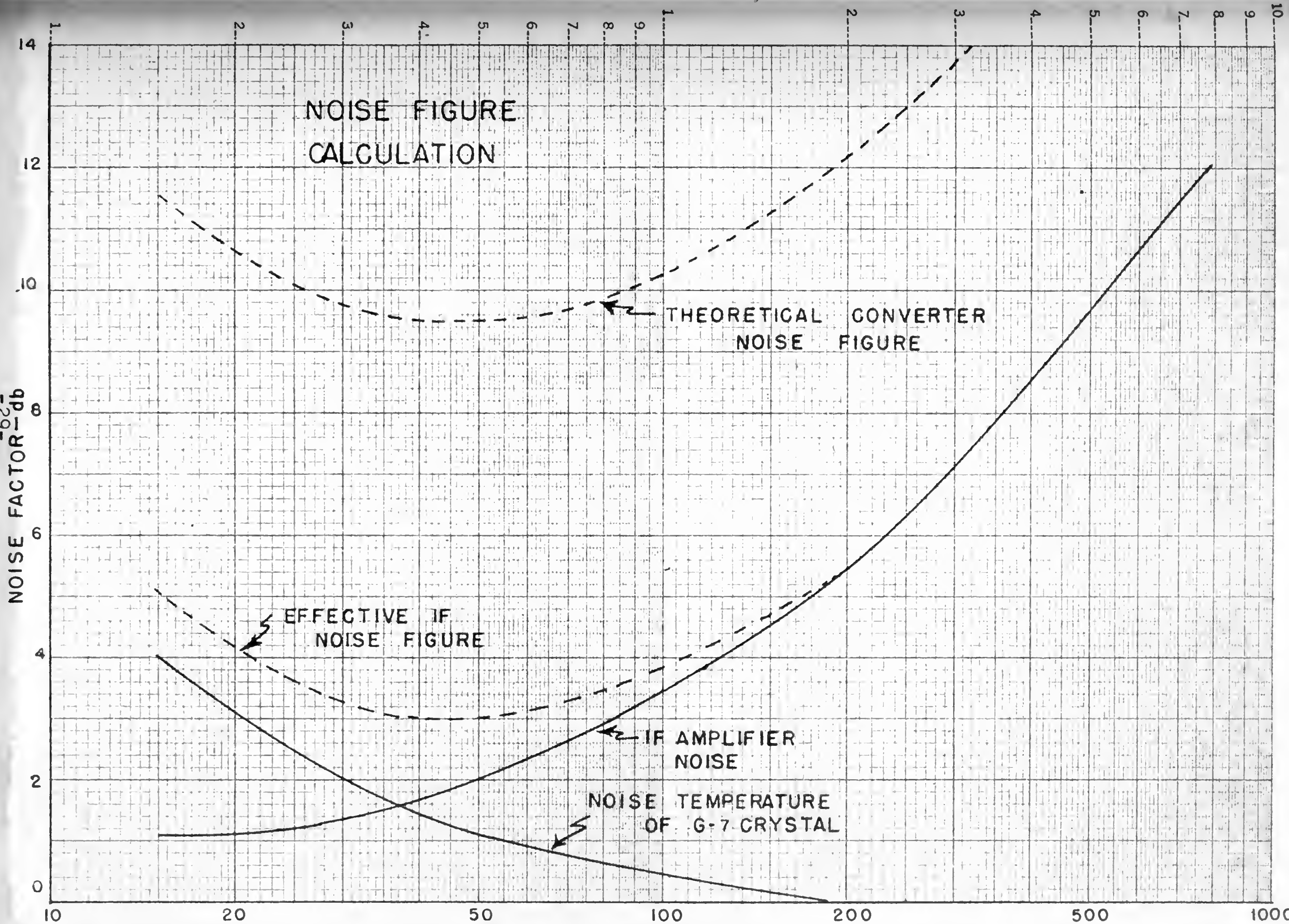

NOISE FIGURE
CALCULATION
THEORETICAL CONVERTER
NOISE FIGURE
EFFECTIVE IF
NOISE FIGURE
IF AMPLIFIER
NOISE
NOISE TEMPERATURE
OF G-7 CRYSTAL
NOISE FACTOR-db
FREQUENCY- MC

Figure 7

Noise factor (db) = crystal mixer loss + i-f noise + crystal noise temperature.

For example: Assume an i-f of 40 Mc and a mixer loss of 6.5 db.

Noise factor = 6.5 db + 1.6 db + 1.4 db = 9.5 db

CHAPTER IV

CURRENT DESIGN DATA

1. General

The information and data included in this section have been added to assist those interested in the actual development and design of a practical u-h-f converter. Much of the foregoing discussion on major performance design considerations in Chapter III has been based upon this material.

2. Available tubes and crystals

One of the latest and most promising tubes to be developed for u-h-f is the 2367A (RCA). This tube is essentially the 6F4 in a 7 pin miniature envelope. As an oscillator, it has been made to cover the entire u-h-f range quite satisfactorily. To date, it is in the experimental stage and is not yet commercially available. When produced, the price is expected to be equivalent to that of the convential miniature triode. Characteristics of the tube are as follows:

Heater voltage	-	6.3 volts
Heater current	-	.225 amps

Direct Interelectrode Capacitances

Grid to Plate	-	1.9 uuf
Grid to Cathode	-	2.2 uuf
Plate to Cathode	-	.45 uuf

Typical Operation

Plate voltage	- 80 volts	(Maximum - 150 volts)
Amplification factor	- 15	
Plate resistance	- 2270 ohms	
Transconductance	- 6600 umhos	
Plate current	- 16 ma	
Cathode resistance	- 150 ohms	

Another tube that has been developed for use in television tuners is a new low noise, medium-mu, twin-triode, the 6BQ7. This tube is commercially available at a reasonable price, and its characteristics make it well suited for use in a "cascode" stage amplifier.

	Triode Unit T_1	Triode T_2
Cgp	1.15 uuf	1.15 uuf
Input Capacitance	2.55 uuf	---
Input (Grounded Grid)	---	4.75 uuf
Output Capacitance	1.30 uuf	---
Output (Grounded Grid)	---	2.40 uuf
Cpk	0.12 uuf	0.12 uuf
C_{hk}	2.3 uuf	2.3 uuf

C (Plate of unit #1 to plate #2) .006

C (Plate of unit #2 to Plate and Grid of #1) .014 uuf

Operating Characteristic

Plate voltage	- 150 volts	(Maximum 250 volts)
Amplification factor	- 35	
Plate resistance	- 5800 ohms	
Transconductance	- 6000 umhos	

Plate current	-	9 ma
Maximum plate current- for grid voltage = -10		100 µamps
Cathode bias resistor-		220 ohms

The miniature magnitron oscillator tube developed by the General Electric Co. has been tried, but has been found to have the following difficulties: (1) magnet placement critical (2) oscillator radiation excessive (3) mode skipping resulting in tracking difficulties.

The beam deflection tube has been tried also as a mixer stage for u-h-f (9). Advantages are; (1) it can be made to have fairly high gain, (2) it has fairly low noise factor (see figure 4). Disadvantages are as follows. It is (1) hard to adjust, (2) costly, (3) critical to voltage changes, (4) still in the laboratory stage.

The 6J4 has been used as an r-f amplifier but its use seems to be of no particular advantage. A new pencil tube, the 5876 (RCA) has shown some promise for r-f amplifier use. Theoretical gain and noise factor curves for grounded grid application from an unpublished report by T. Murakami of RCA are included in figures 8 and 9.

The Western Electric 416A may have application for special service in a few costly installations, however, tuning remains a difficult problem. Theoretical gain and noise factor curves for grounded grid application are included in figures 10 and 11. Note (see appendix B for gain and noise factor equations for grounded grid amplifer calculations).

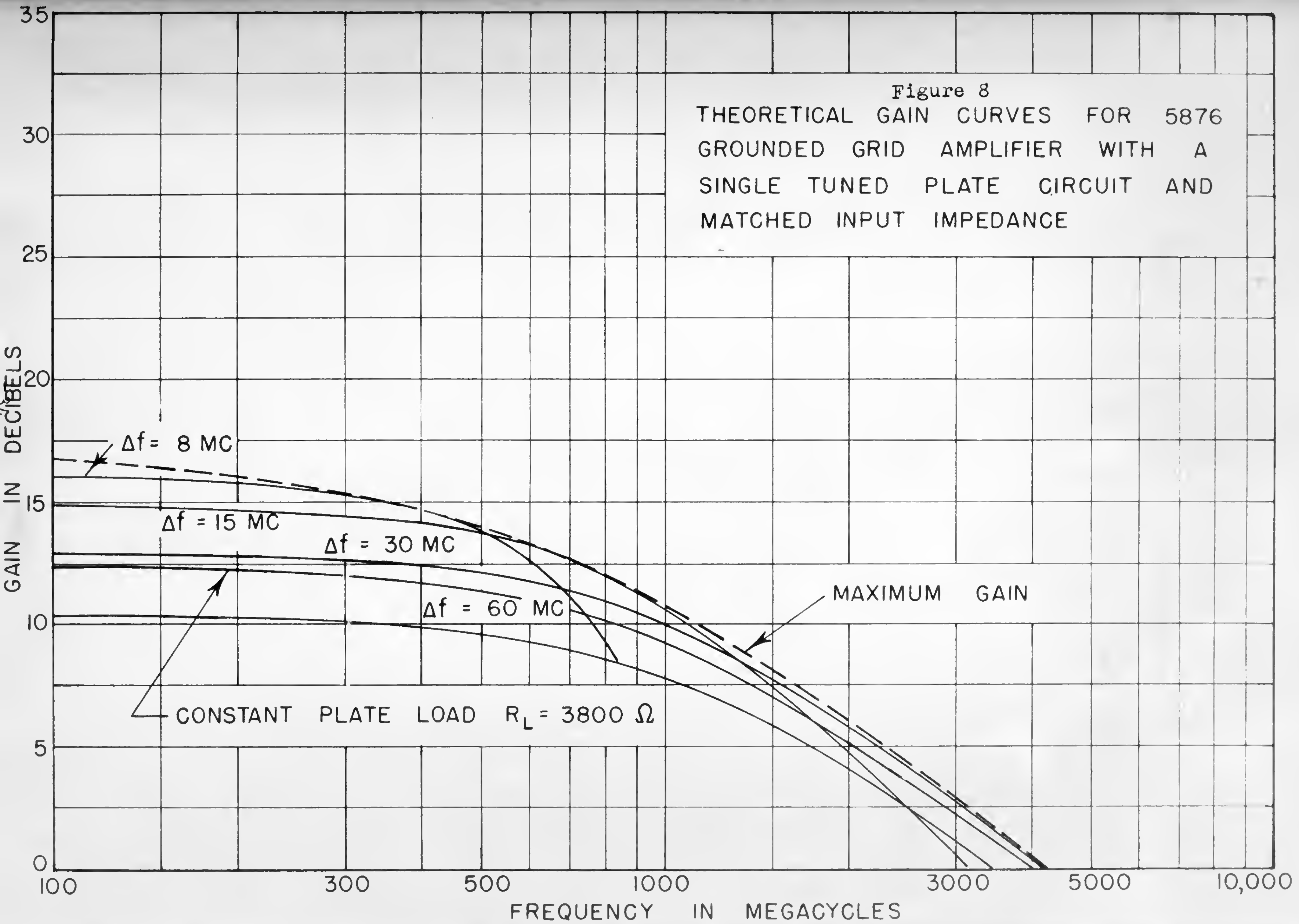


Figure 8
THEORETICAL GAIN CURVES FOR 5876 GROUNDED GRID AMPLIFIER WITH A SINGLE TUNED PLATE CIRCUIT AND MATCHED INPUT IMPEDANCE
Δf = 8 MC
Δf = 15 MC
Δf = 30 MC
Δf = 60 MC
MAXIMUM GAIN
CONSTANT PLATE LOAD R_L = 3800 Ω
GAIN IN DECIBELS
FREQUENCY IN MEGACYCLES
35
30
25
20
15
10
5
0
100
300
500
1000
3000
5000
10,000

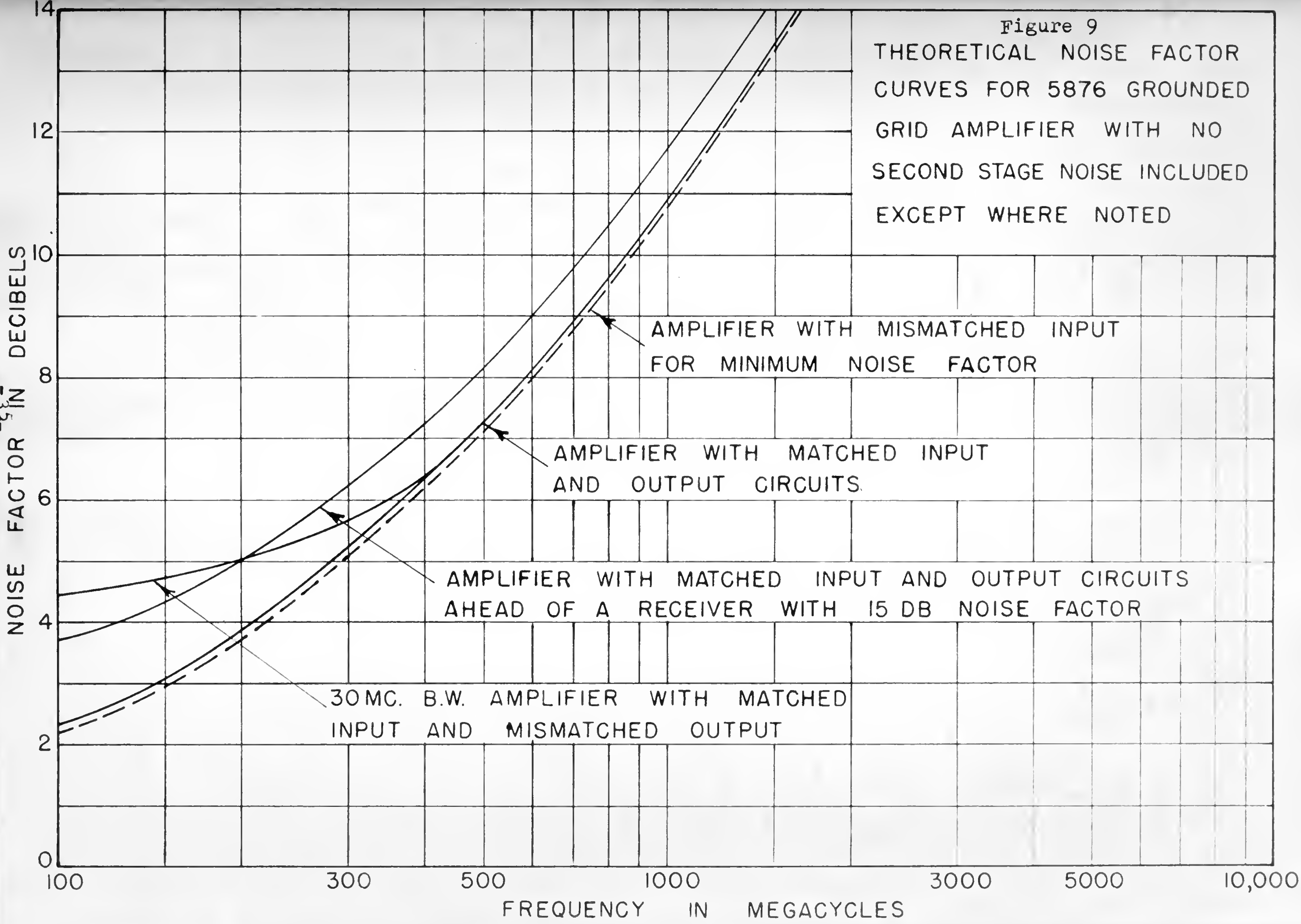


Figure 9
THEORETICAL NOISE FACTOR CURVES FOR 5876 GROUNDED GRID AMPLIFIER WITH NO SECOND STAGE NOISE INCLUDED EXCEPT WHERE NOTED

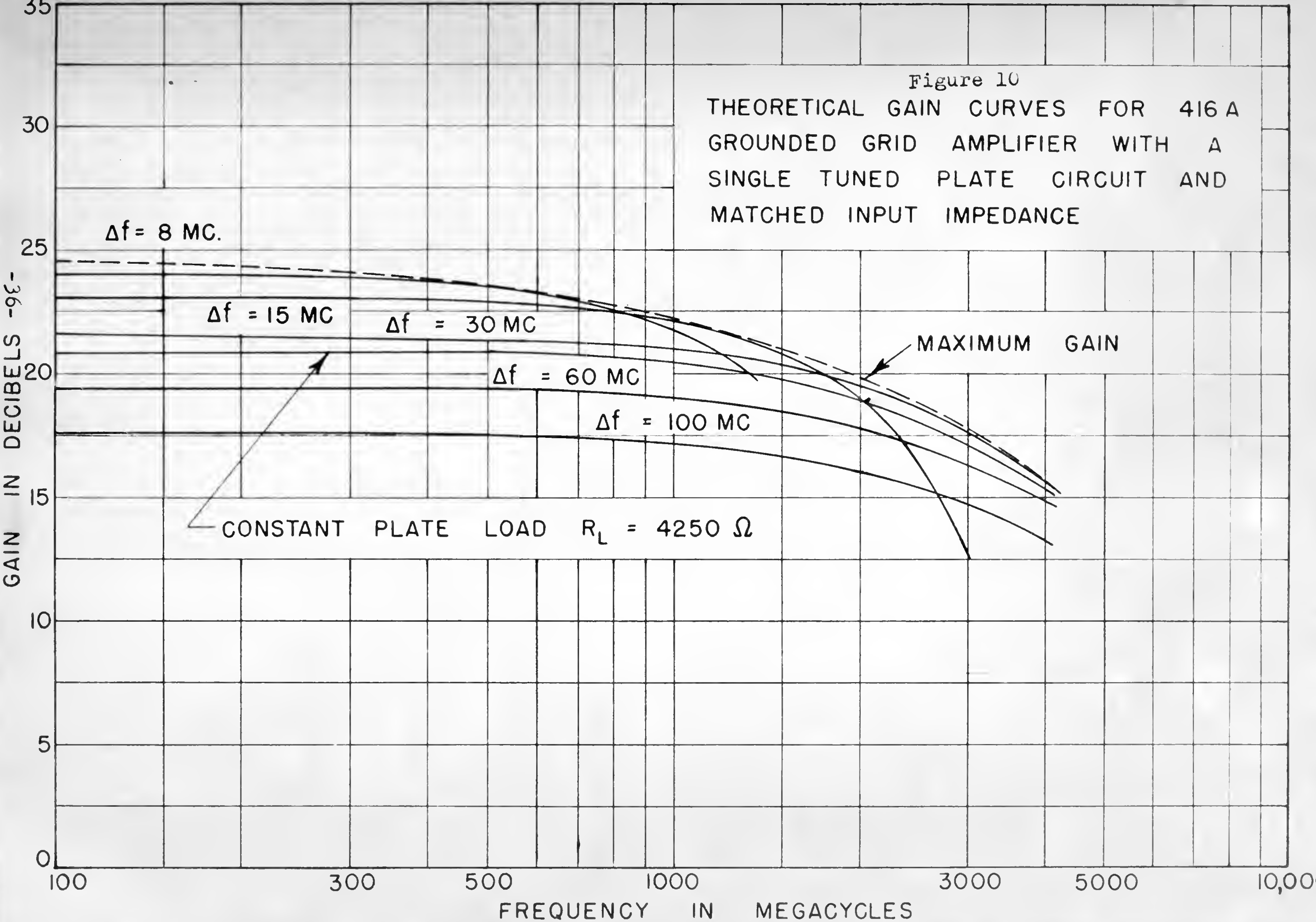


Figure 10
THEORETICAL GAIN CURVES FOR 416 A GROUNDED GRID AMPLIFIER WITH A SINGLE TUNED PLATE CIRCUIT AND MATCHED INPUT IMPEDANCE
Δf = 8 MC.
Δf = 15 MC
Δf = 30 MC
Δf = 60 MC
Δf = 100 MC
MAXIMUM GAIN
CONSTANT PLATE LOAD R_L = 4250 Ω
GAIN IN DECIBELS
FREQUENCY IN MEGACYCLES
35
30
25
20
15
10
5
0
100
300
500
1000
3000
5000
10,000

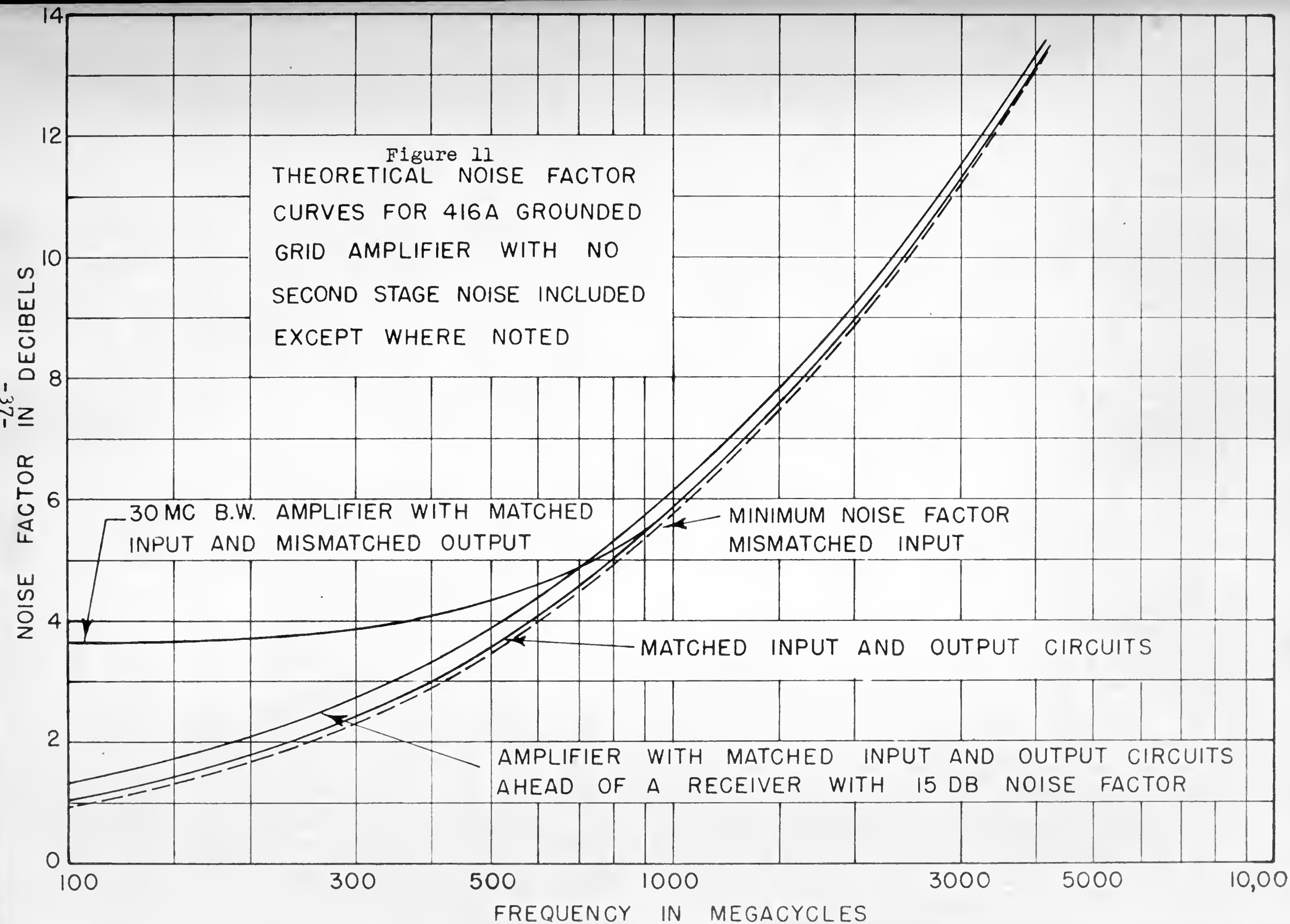


Figure 11
THEORETICAL NOISE FACTOR CURVES FOR 416A GROUNDED GRID AMPLIFIER WITH NO SECOND STAGE NOISE INCLUDED EXCEPT WHERE NOTED
30 MC B.W. AMPLIFIER WITH MATCHED INPUT AND MISMATCHED OUTPUT
MINIMUM NOISE FACTOR MISMATCHED INPUT
MATCHED INPUT AND OUTPUT CIRCUITS
AMPLIFIER WITH MATCHED INPUT AND OUTPUT CIRCUITS AHEAD OF A RECEIVER WITH 15 DB NOISE FACTOR
NOISE FACTOR IN DECIBELS
FREQUENCY IN MEGACYCLES
0
2
4
6
8
10
12
14
100
300
500
1000
3000
5000
10,000

Input loading curves figure 12 for the 416A, 5876, and several other high frequency triodes are included to show the variation in loading as a function of frequency

Crystals available for mixer service have until recently been of the silicon variety such as the 1N21B, 1N21C, etc. Developments in germanium have produced two crystals, the 1N72 (G-7, General Electric), and the CK710 (Raytheon) which have approximately the same relative mixer losses as the 1N21B as shown in figure 13. On the basis of cost and performance, the germanium probably has the advantage. Recent tests on a selected group of 1N72 crystals indicate an average mixer loss equivalent to that of the 1N21B. The germanium crystals, in general, are capable of withstanding a higher inverse voltage (G-7 5 volts, CK710 & 1N21B 2 volts), are self healing and cost considerably less than silicon crystals. To date, efforts to correlate the d-c characteristics, figure 14, of germanium crystals with the conversion loss have failed.

3. Tuning and tracking

Methods of tuning u-h-f converters may be divided into two types (1) continuously variable, and (2) fixed frequency. Continuous type of tuning is generally accomplished (1) by varying the inductance (sliding contact, sliding core, moving vane), (2) by varying the capacity, or (3) by a combination of both (such as the butterfly circuit).

Fixed frequency converters cover such types as turret tuners (rotary or linear motion) containing separate tuned strips or single frequency units.

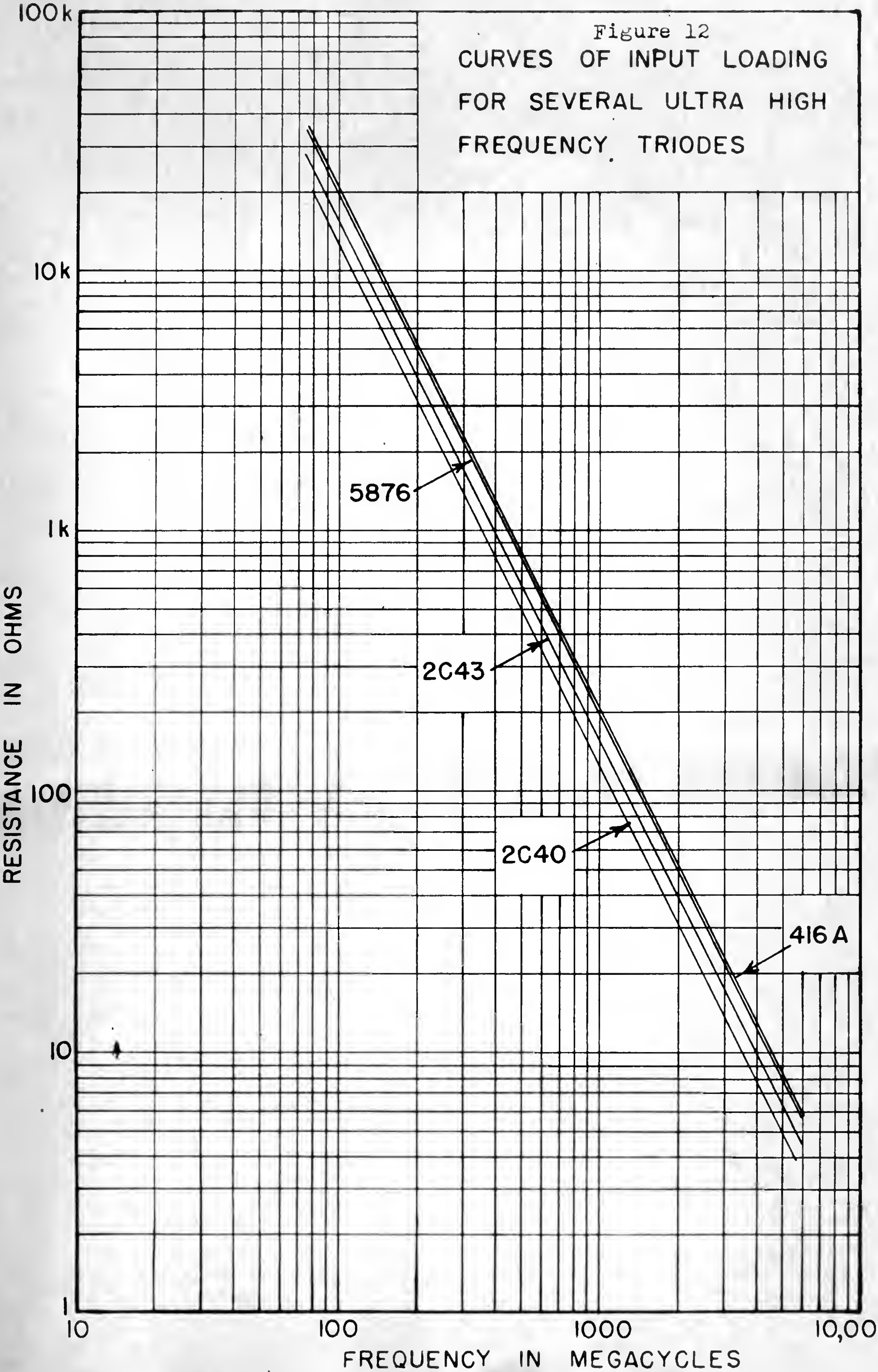


Figure 12
CURVES OF INPUT LOADING
FOR SEVERAL ULTRA HIGH
FREQUENCY TRIODES
5876
2C43
2C40
416 A
RESISTANCE IN OHMS
100k
10k
1k
100
10
1
10
100
1000
10,000
FREQUENCY IN MEGACYCLES

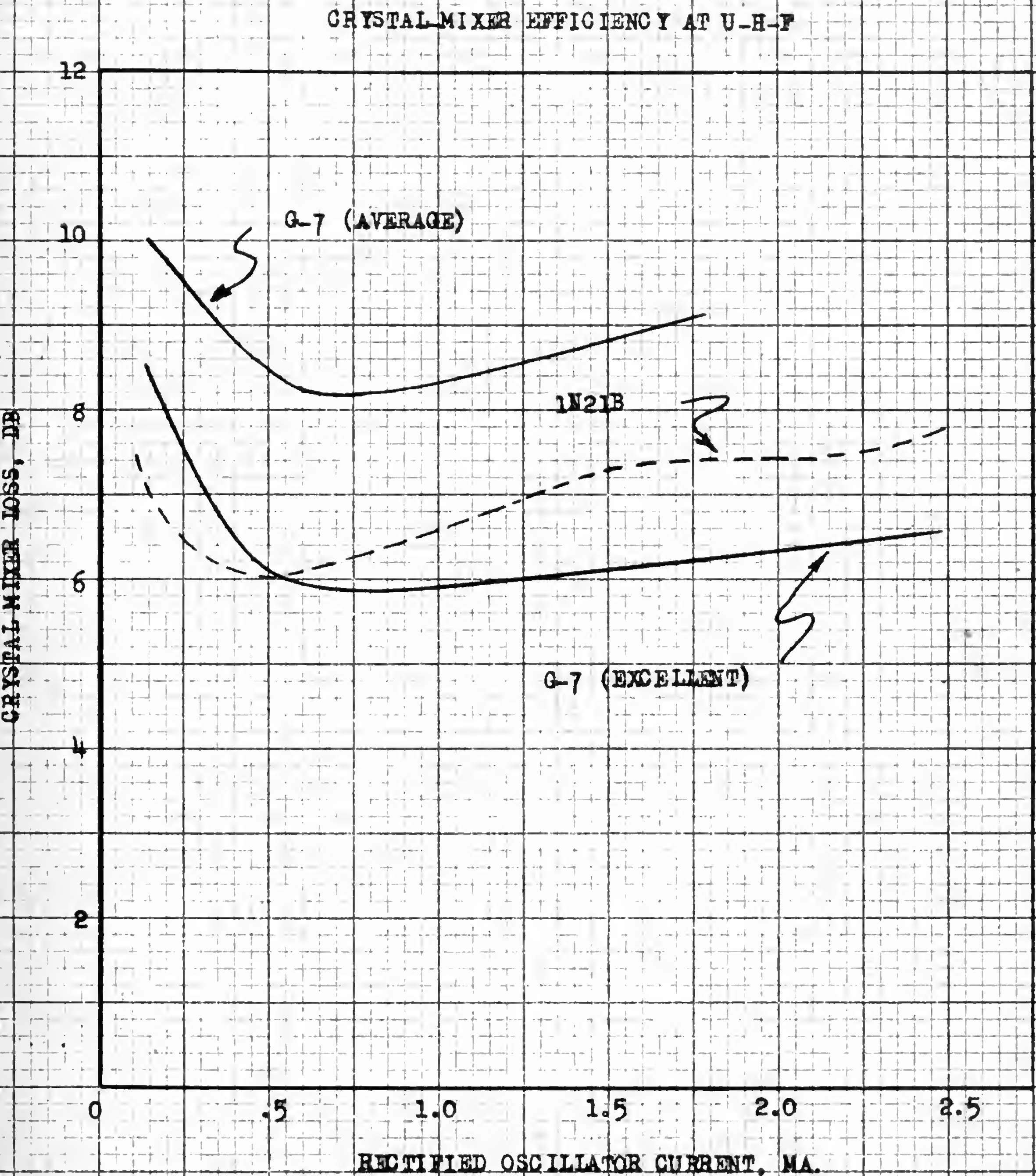
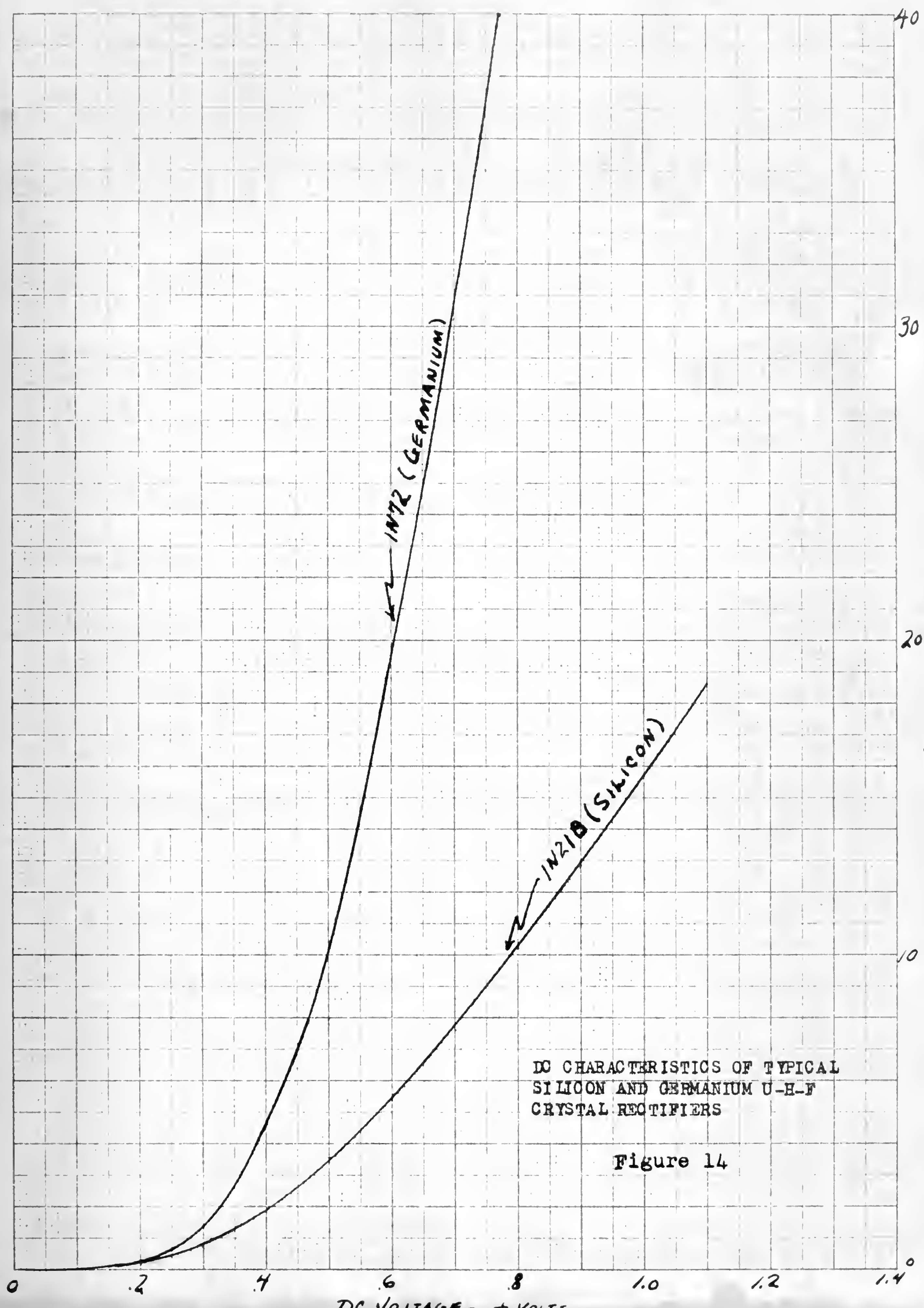

CRYSTAL-MIXER EFFICIENCY AT U-H-F
CRYSTAL-MIXER LOSS, DB
12
10
8
6
4
2
0
.5
1.0
1.5
2.0
2.5
G-7 (AVERAGE)
1N21B
G-7 (EXCELLENT)
RECTIFIED OSCILLATOR CURRENT, MA.

Figure 13



DC CHARACTERISTICS OF TYPICAL SILICON AND GERMANIUM U-H-F CRYSTAL RECTIFIERS

Figure 14

Listed below are some of the various type circuits which might be considered for u-h-f converter design. Also see figure 15 in which C represents either tube shunting capacitance.

1. Coil and capacitor - Up to 400 Mc, used with miniature or acorn tubes.

   Disadvantages:

   1. Inductance appears in the capacitor.
   2. Not usable above 400 Mc.
   3. Quantity production difficult.

2. Butterfly - 100-1000 Mc (3000 Mc possible) symmetrical circuit, 3 to 1 frequency coverage, L and C both change.

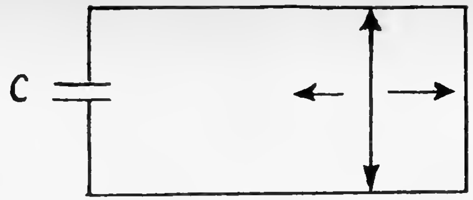
   Disadvantages:

   1. Spurious modes.
   2. Tube mounting difficult.
   3. Ganging difficult.
   4. 90° effective rotation.
   5. Large.
   6. Two tuned elements.

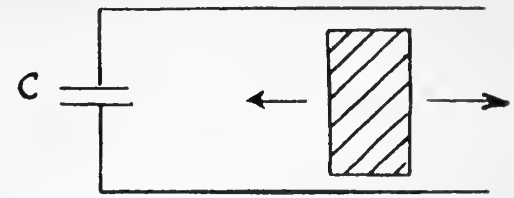
3. Semi-butterfly - 100 to 700 Mc used with miniature acorn or lighthouse tubes, L and C both change, 180° rotation, tube mounting and ganging not difficult.

   Disadvantages:

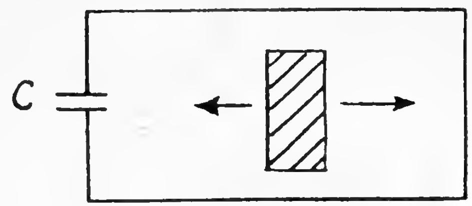
   1. Spurious modes.
   2. Frequency coverage limited.
   3. Non-symmetrical.
   4. Requires shielding.



a. SLIDING SHORT

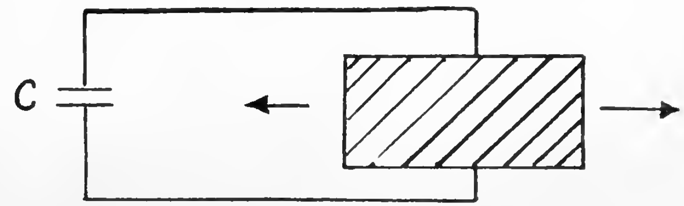


b. CAPACITY SHORT



c. VARIABLE CAPACITY LOADING

d. VARIABLE END-CAPACITY LOADING



e. VARIABLE SURGE IMPEDANCE

TUNING METHODS

Figure 15

4. Coaxial line-up to 3000 Mc or even higher used with lighthouse or klystron tubes, constant Z_0, excellent Q possible, wide range, self shielding.

Disadvantages;

1. Sliding contacts or noncontacting plunger.
2. Ganging difficult.
3. Harmonics possible

5. Hairpin circuit - 500-1000 Mc. Fairly high Q, 2 to 1 frequency coverage, ganging not difficult, easily tuned.

Disadvantages:

1. Mechanical difficulties.
2. Reflection at high frequency end.
3. Requires shielding.

6. Split cylinder - 300 up to 1000 Mc, ganging not too difficult, easily tuned.

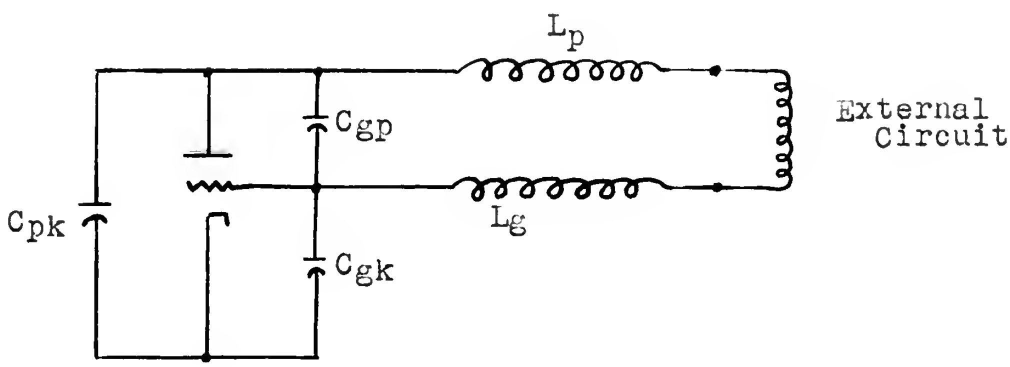
Disadvantages:

1. Narrow frequency coverage.
2. Relatively low Q.
3. Long time frequency drift.
4. Requires shielding.

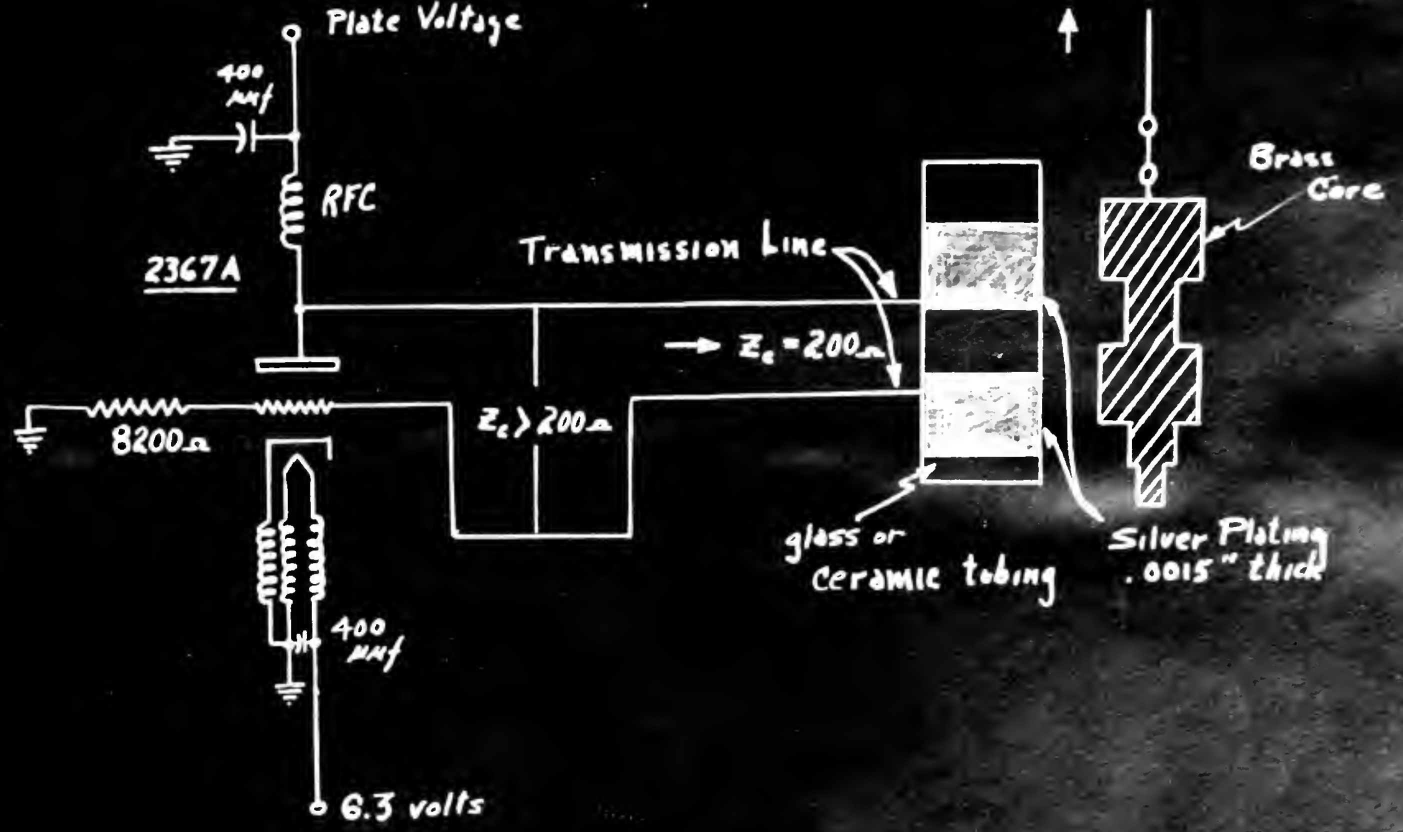
7. Series resonant circuit (12) (16) (17) - up to 1000 Mc wide frequency coverage, preferably used with miniature tubes such as 2367A, minimum number of parts. See figure 17.

4. Oscillator data

An oscillator employing the 2367A in a series resonant circuit with variable capacity tuning is shown in figure 16. This oscillator has been described by F. J. Kamphoefner (13) and J. M. Pettit (18) in their papers on u-h-f oscillators. Transit time effects and self resonances of the tube elements are not limiting factors to the upper limit of oscillation. There are a minimum number of parts since there is no external r-f path between plate and cathode, or grid and cathode. The discontinuity in the line is to compensate for the unbalance to ground when the slug is moved outward. The equivalent circuit diagram is shown below.



Figures 17 and 18 have been included to aid in the computation of local oscillator radiation. For example, assume 5,000 uv signal across a matched resistance R_o. Entering figure 18 this corresponds to a radiated power of .08 microwatts or a field strength of 65 microvolts per meter at a distance of 100 feet. A field strength of 65 microvolts/meter from figure 18 is equivalent to a



Oscillator circuit of a u-h-f tuner

FIGURE 16

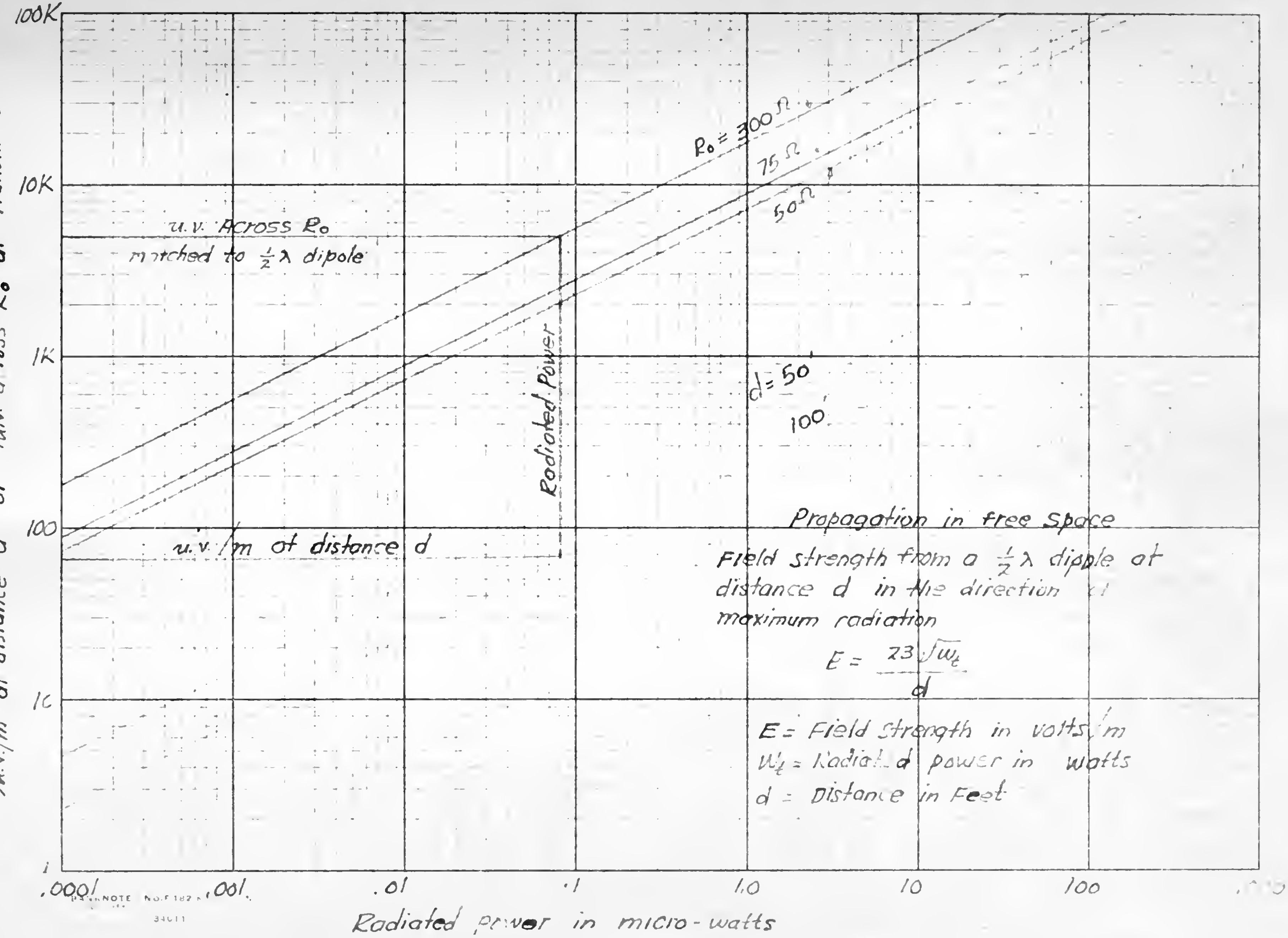
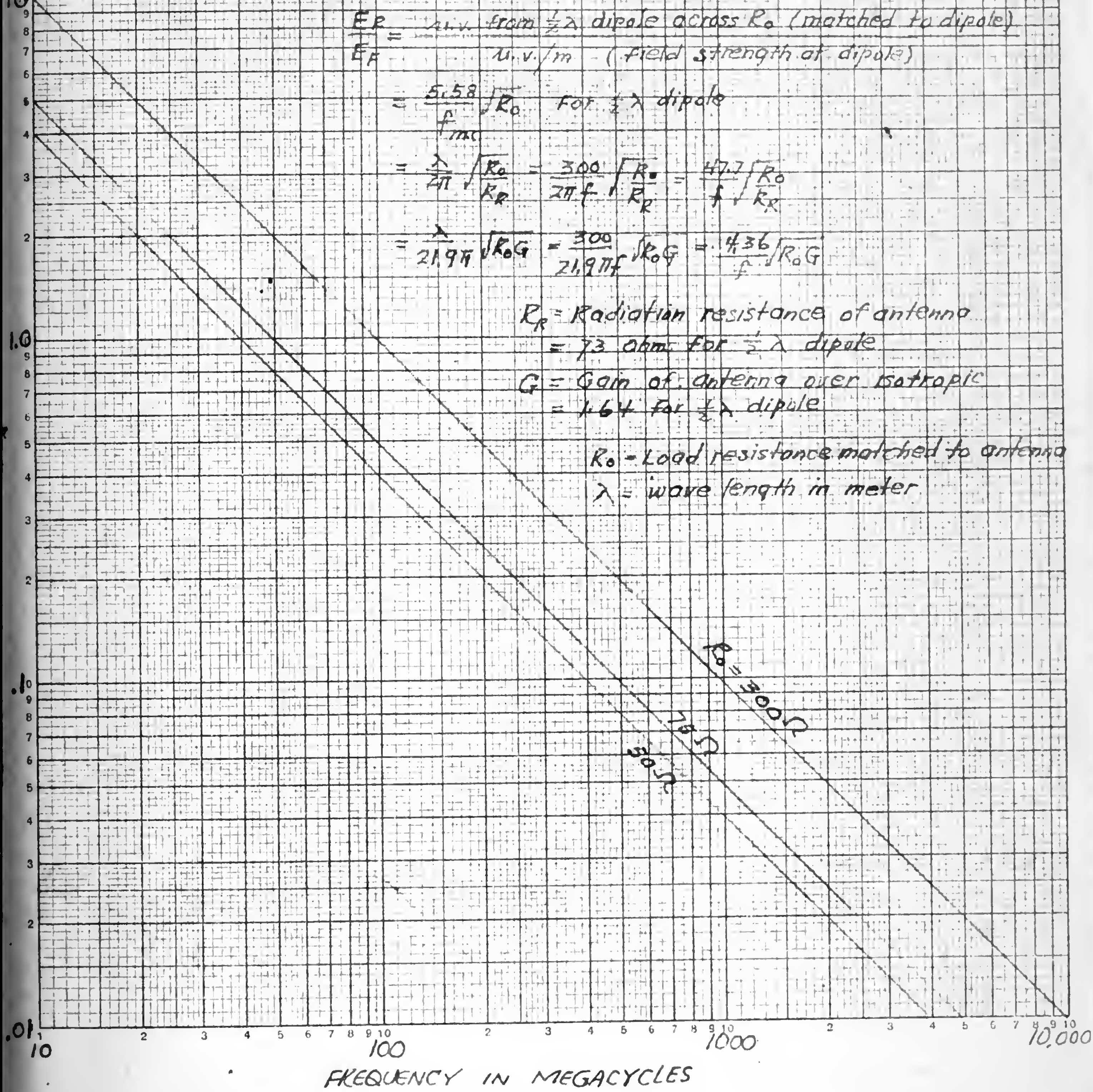

100K
10K
1K
100
10
1
.0001
.001
.01
.1
1.0
10
100
R_o = 300 Ω
75 Ω
50 Ω
d = 50'
100'
u.v. Across R_o matched to $\frac{1}{2}\lambda$ dipole
u.v./m at distance d
Radiated Power
Propagation in free Space
Field strength from a $\frac{1}{2}\lambda$ dipole at distance d in the direction of maximum radiation
$E = \frac{23\sqrt{W_t}}{d}$
E = Field Strength in volts/m
W_t = Radiated power in watts
d = Distance in Feet
u.v./m at distance d or u.v. across R_o at transmitter (radiating receiver)
Radiated power in micro-watts

Figure 17



$\frac{E_R}{E_F} = \frac{u.v.\text{ from } \frac{1}{2}\lambda \text{ dipole across } R_o \text{ (matched to dipole)}}{u.v./m \text{ (field strength at dipole)}}$
$= \frac{5.58}{f_{mc}}\sqrt{R_o}$ for $\frac{1}{2}\lambda$ dipole
$= \frac{\lambda}{2\pi}\sqrt{\frac{R_o}{R_R}} = \frac{300}{2\pi f}\sqrt{\frac{R_o}{R_R}} = \frac{47.7}{f}\sqrt{\frac{R_o}{R_R}}$
$= \frac{\lambda}{21.9\pi}\sqrt{R_o G} = \frac{300}{21.9\pi f}\sqrt{R_o G} = \frac{4.36}{f}\sqrt{R_o G}$
R_R = Radiation resistance of antenna
= 73 ohm for $\frac{1}{2}\lambda$ dipole
G = Gain of antenna over isotropic
= 1.64 for $\frac{1}{2}\lambda$ dipole
R_o = Load resistance matched to antenna
λ = wave length in meter
$R_o = 300\Omega$
75Ω
50Ω
10
1.0
.1
.01
10
100
1000
10,000
FREQUENCY IN MEGACYCLES

Figure 18

received signal of 6.5 microvolts from a 1/2 λ dipole across a matched load of 300 ohms at 1000 megacycles. At 500 megacycles this same field strength also produces 6.5 microvolts across a matched load of 75 ohms.

5. Relative magnitude of various spurious responses.

A summarization of the relative magnitudes of the spurious responses as outlined in chapter III are presented so that proper selectivity characteristics of u-h-f receivers and converters can be determined.

A. Spurious responses formed by the harmonics generated in the mixer during process of mixing, both single-frequency and two-frequency varieties (IN72 germanium and 1N21B crystal rectifier used as u-h-f mixer).

(1) The equivalent mixer efficiency e_1 in responding to a direct f_i signal, and the equivalent mixer efficiency e_{m1} in responding to the image-frequency signals are both independent of the strength of the interfering signal. The ratio e_1/e_n is about 5 or 6 db depending upon the type of crystal rectifier being used, while the ratio e_{m1}/e_n is generally 0 db.

(2) The equivalent mixer efficiency e_2 in responding to a $\frac{1}{2}$ f_i signal and the equivalent mixer efficiency e_{m2} in responding to the $\frac{1}{2}$ i-f and $\frac{1}{2}$ image signals resulting from

the local oscillator signal and the interfering signal are approximately directly proportional to the strength of the interfering signals.

(3) The equivalent mixer efficiency e_3 in responding to a 1/3 f_i signal and the equivalent mixer efficiency e_{m3} in responding to the 1/3 i-f and 1/3 image signals are approximately proportional to the square of the strength of the interfering signals.

(4) The spurious responses formed by the 4th harmonic generated in the mixer during the process of mixing are relatively unimportant, and those formed by the 5th or higher order harmonics of the mixer can be disregarded for all practical purposes.

(5) Silicon crystal rectifiers such as 1N21B, in general, are more susceptable to spurious responses compared with the germanium crystal rectifiers. Receivers using a germanium crystal mixer such as the 1N72 type can stand an undesired response formed by any harmonic of the mixer twice as strong in field intensity as for receivers using a silicon crystal mixer for same picture quality if the other characteristics of both receivers are exactly the same.

(6) To minimize the spurious responses of a u-h-f television receiver formed by the harmonics generated in the mixer during the process of mixing, the bandwidth of the radio frequency selective circuits preceding the mixer must be considerably less than half of the intermediate frequency.

(7) The effects of the strengths of the interfering signals appearing across the input terminals of the mixer on the equivalent mixer efficiencies in responding to the interfering signal of the two-frequency variety formed by mixer harmonics are indicated in figures 19 and 20 for 1N21B and 1N72 crystal rectifiers respectively. Suppose that a ratio of the desired to the undesired signal of at least 30 db is required for a good quality picture, and that a difference in field strength between the undesired and the desired signal of 40 db is allowed. The selectivity of u-h-f television receiver at frequencies in the neighborhood of the desired-signal frequency must then exhibit the characteristics given in the following table.

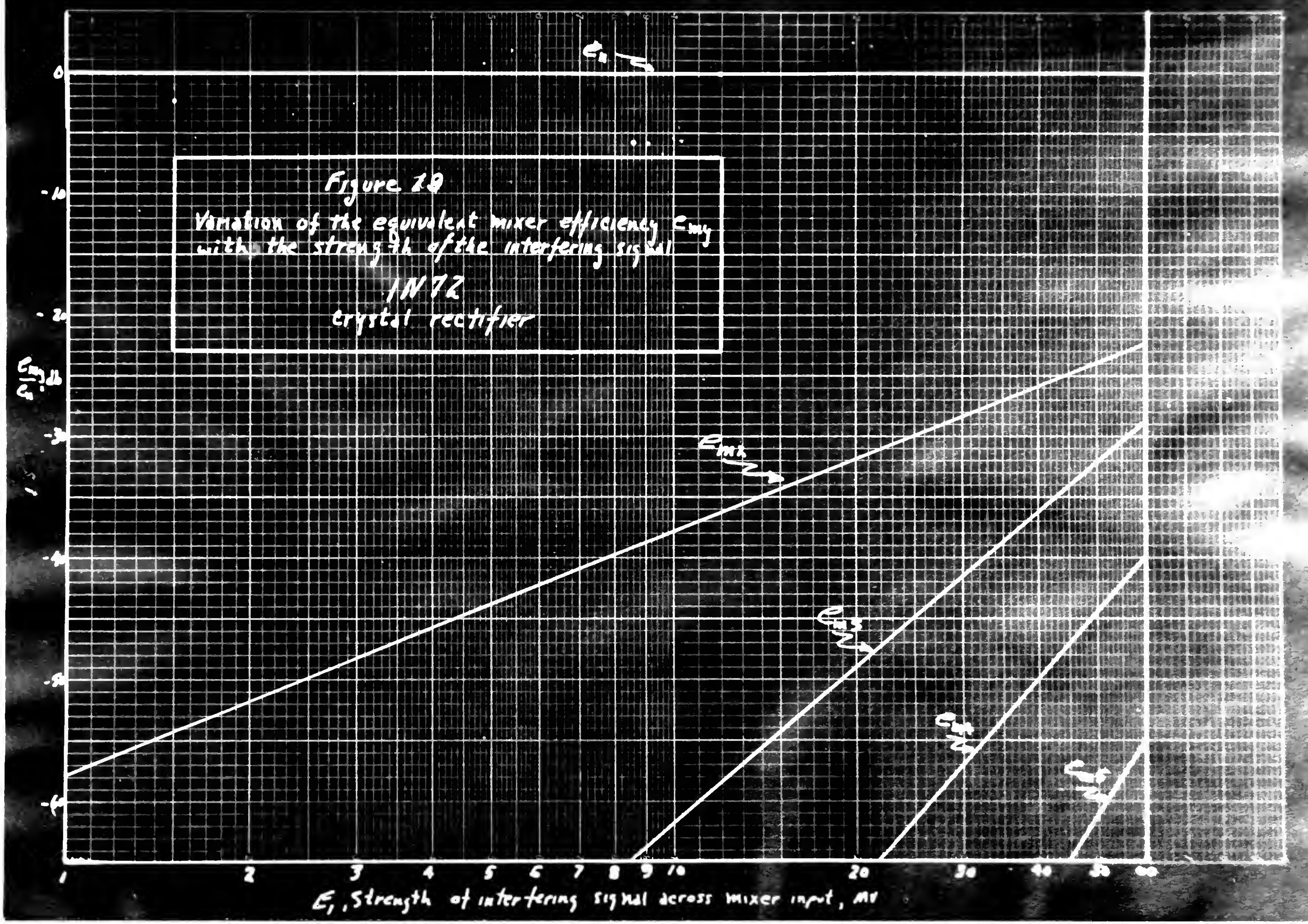


Figure 19
Variation of the equivalent mixer efficiency ϵ_{my} with the strength of the interfering signal
1N72
crystal rectifier
ϵ_{mx}
ϵ_{m3}
$\frac{\epsilon_{my}}{\epsilon_{o}}$ db
0
-10
-20
-30
-40
-50
-60
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
E_1, Strength of interfering signal across mixer input, mv

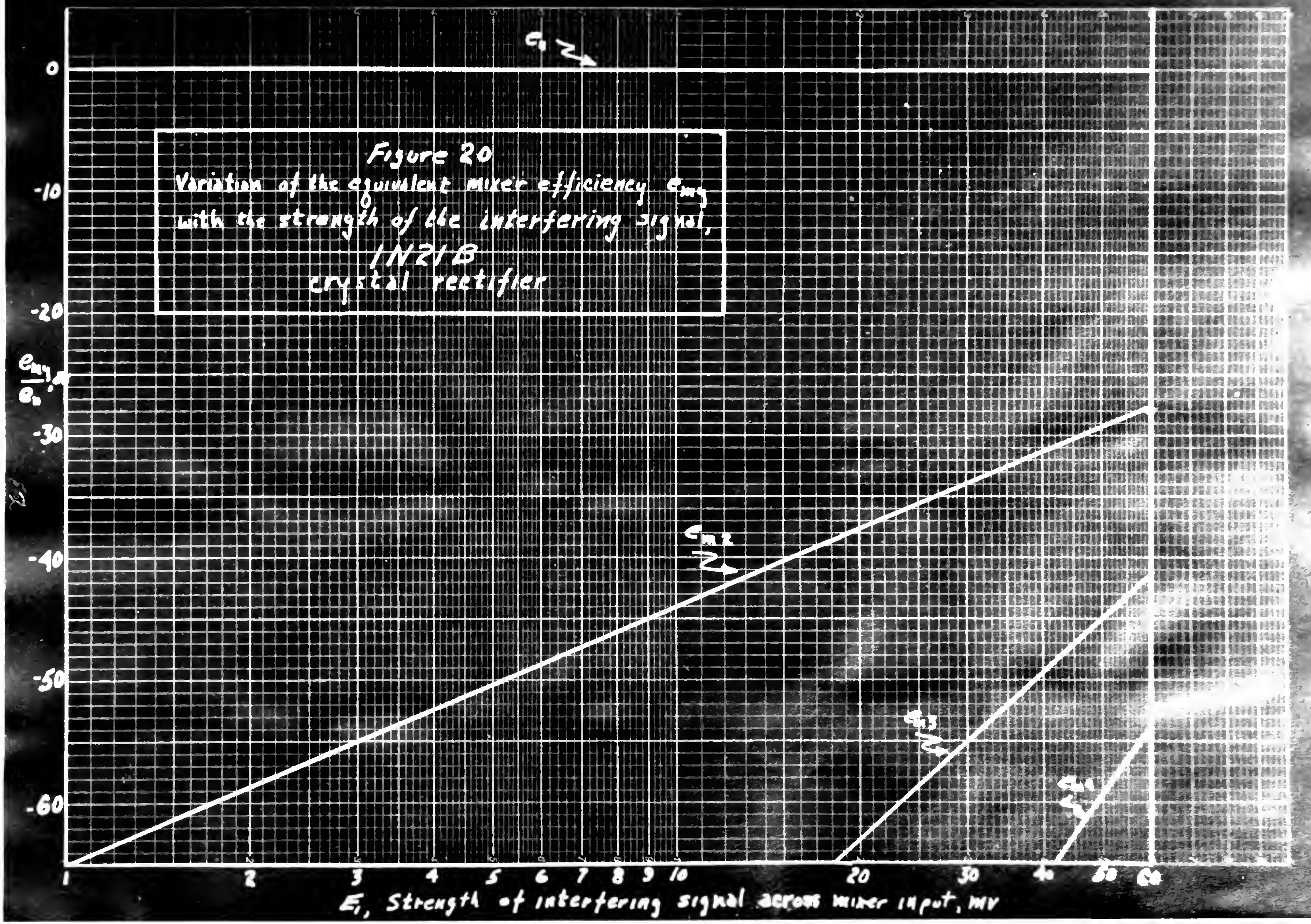


Figure 20
Variation of the equivalent mixer efficiency e_{my} with the strength of the interfering signal,
1N21B
crystal rectifier
e_0
e_{m2}
e_{m3}
e_{m4}
0
-10
-20
-30
-40
-50
-60
$\frac{e_{my}}{e_0}$, db
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
E_1, Strength of interfering signal across mixer input, mv

Table I

Required receiver selectivity at frequencies in the neighborhood of the desired-signal frequency, assuming 25 mv interfering signal.

Mixer Harmonic	Interfering Signal Frequency	$\frac{e_{my}}{e_n}$ 1N72	$\frac{e_{my}}{e_n}$ 1N21B	Receiver Selectivity Required db 1N72	Receiver Selectivity Required db 1N21B
1st	w_0-w_i	0 db	0 db	0 db	0 db
	w_0+w_i	0	0	70	70
2nd	$w_0 \pm \frac{w_i}{2}$	-36	-30	-34	-40
3rd	$w_0 \pm \frac{w_i}{3}$	-58	-46	-12	-24
4th	$w_0 \pm \frac{w_i}{4}$	high	-62	0	-8
5th	$w_0 \pm \frac{w_i}{5}$	high	high	0	0

B. Spurious responses formed by or in conjunction with harmonics of the local oscillator.

(1) The equivalent mixer efficiency e_{ox} relative to e_n depends upon the order of harmonic of the local oscillator, the amount of oscillator injection, and the type of crystal rectifier being used as mixer.

(2) High order harmonics of the local oscillator must be considered in the design of u-h-f receivers insofar as spurious responses are concerned. At u-h-f the conventional selective circuits may have points of low rejection at frequencies far off resonance due to couplings of nearby objects or circuits.

(3) The equivalent mixer efficiency e_{oxmy} relative to e_n may be determined by considering two factors, e_{ox}/e_n and e_{my}/e_n. independently. $\frac{e_{oxmy}}{e_x} = \frac{e_{ox}}{e_n} \cdot \frac{e_{my}}{e_n}$

(4) The amount of oscillator injection has less effect on the equivalent mixer efficiency e_{ox} for silicon crystals rectifiers than it does for germanium crystal rectifiers.

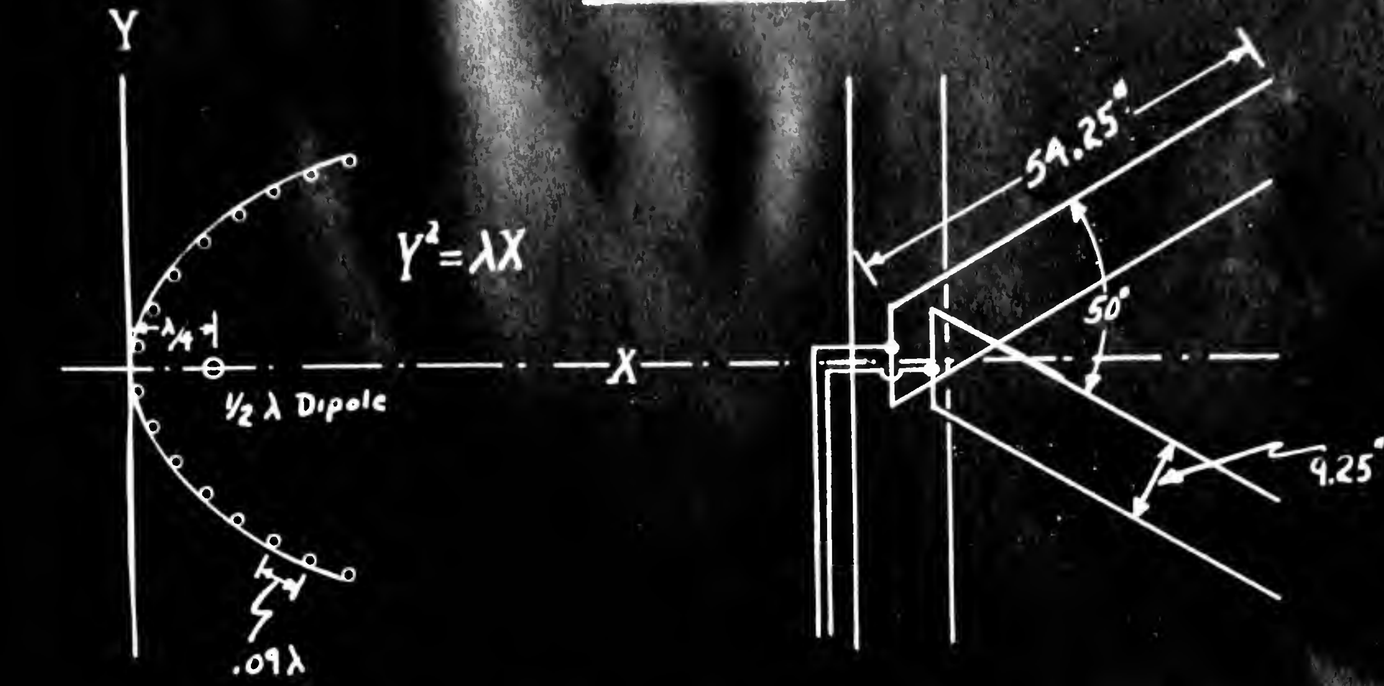
6. Lead in

For the very-high-frequency region, the balanced input using 300 ohm twin lead-in has proven quite successful. At ultra-high-frequency use of the same system, however, results in many difficulties not experienced previously. Capacitive effects become quite pronounced. Such things as lead dress, i.e. placement of lead-in, water on the lead in, lightening arrestor placement, stray pickup, etc. pose serious problems. Use of tubular twin lead is not much improvement over the flat line.

Unbalanced lead, such as RG-59/U however, does permit good shielding and weather proofing. It has the advantage of less attenuation than twin lead and will match directly the half wave dipole. Unfortunately, the cost of such shielded lead-in cable is considerably more than the cost of the conventional twin lead-in used for present v-h-f installations.

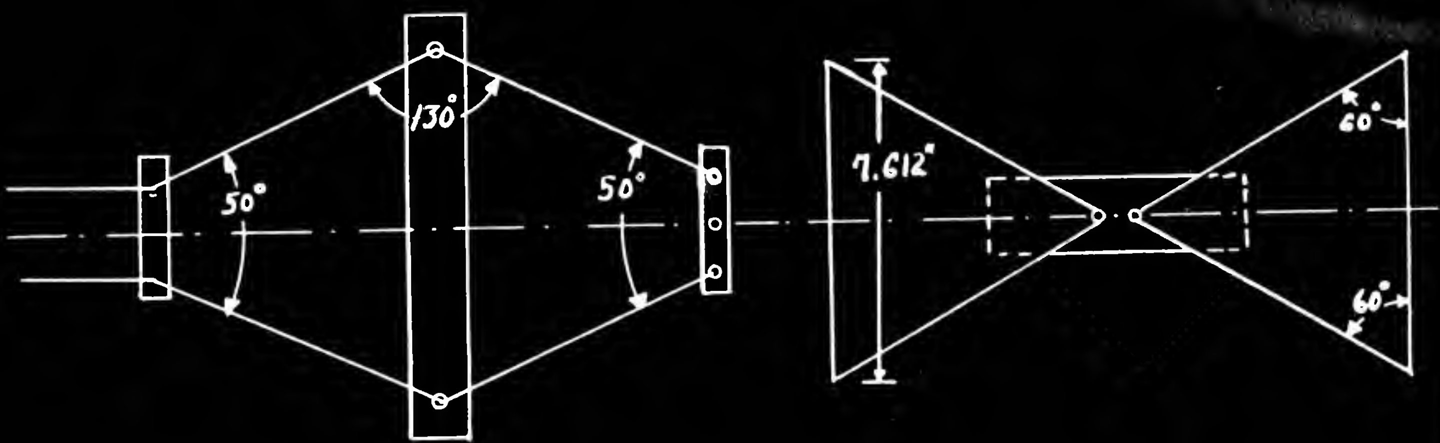
7. Antennas

During the Bridgeport tests, four types of antennas were used. See figure 21.



½λ DIPOLE AND PARABOLIC REFLECTOR

DUAL-VEE



RHOMBIC

FAN

FIGURE 21

Measured gains at 530 Mc over a $1/2\lambda$ dipole were as follows:

Parabola - 7.5 db

Dual-vee - 5.7 db

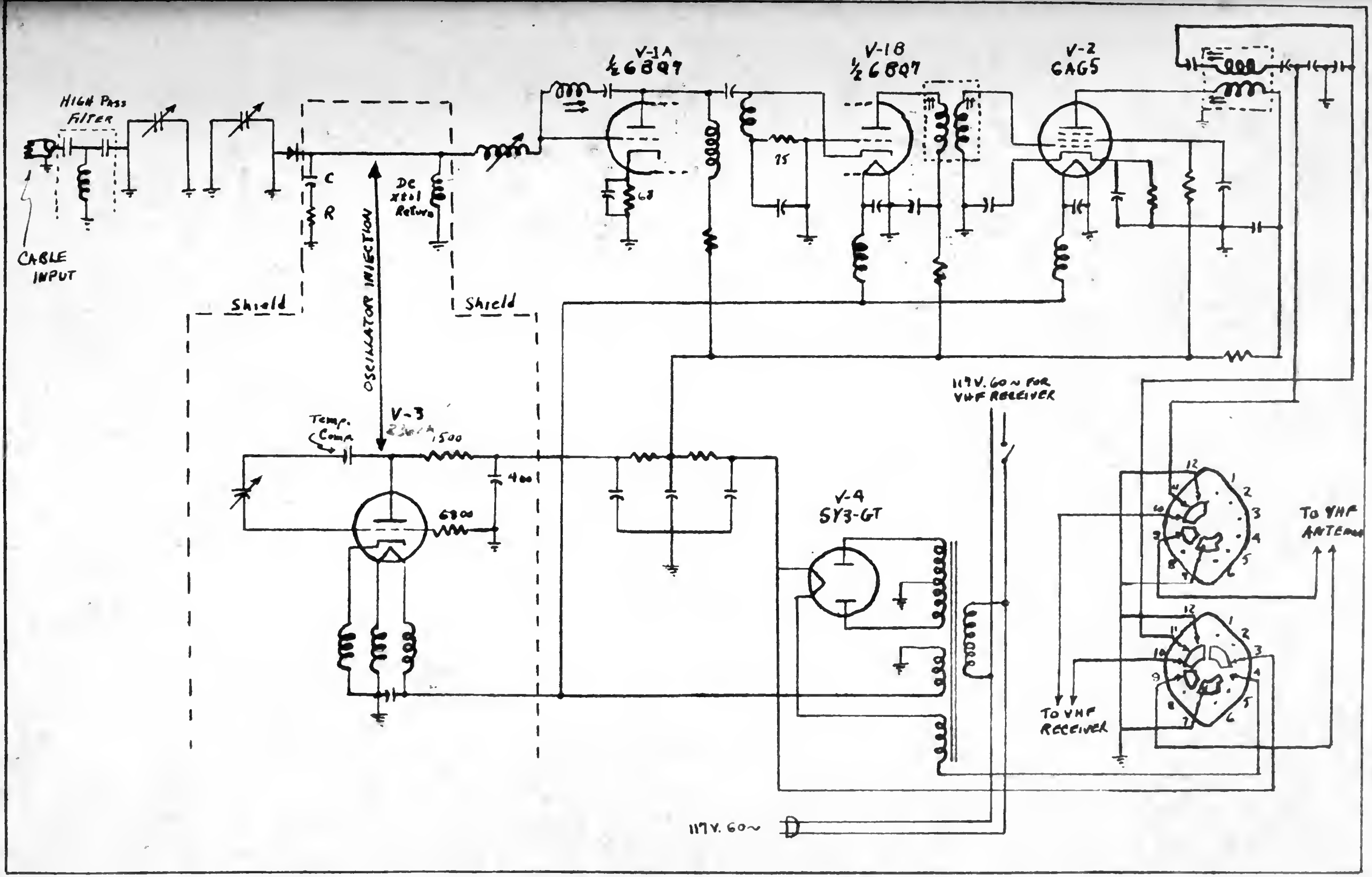
Rhombic - 3.6 db

U-h-f fan- .8 db

The Dual-Vee seems to be best compromise between performance and simplicity.

Transmission lines used in these tests were:

		line loss/100' normal weather
Amphenol tubular	14-076	2.5 db
	RG 8/U	6.5 db
	RG 59/U	9.4 db



U.H.F. CONVERTER

Figure 22

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APPENDIX A

Median field intensities in db above luv/m required to overcome receiver noise for "Grade B" service were computed as follows:

		2-6	7-13	14-83
(1)	Thermal Noise (db)[1]	7 db	7 db	7 db
(2)	Receiver Noise Figure	12 db	12 db	15 db
(3)	Peak Visual Carrier /RMS Noise	30 db	30 db	30 db
(4)	Transmission Line Loss[2]	1 db	2 db	5 db
(5)	Antenna Effective Length[3]	-9 db	0 db	3 db
(6)	Local Field Intensity	41 db	51 db	60 db
(7)	50% Terrain Factor	0 db	0 db	0 db
(8)	90% Fading Factor[4]	6 db	5 db	4 db
(9)	Median Field Intensity	47 db	56 db	64 db
		220uv/m	632 uv/m	1620 uv/m

(1) Reference level in db above 1/uv across 300 Ω impedance.
(2) Transmission line assumed to consist of 50 ft. of 300 ohm twin lead cable.
(3) Antenna assumed to have 6 db gain compared to 1/2 λ dipole for channel 2-13 antenna, and 13 db gain for channel 14-83.
(4) 90% time fading factor - signals received 90% of the time irrespective of fading.

[illegible]

APPENDIX B

RELATION BETWEEN INTERMEDIATE FREQUENCY AND OSCILLATOR RADIATION

Assuming a converter with one r-f tuned circuit with oscillator injection at the i-f end of the crystal mixer, oscillator radiation is reduced as the i-f is increased for the same r-f bandwidth according to the following relations.

f_i = intermediate frequency

f_s = signal frequency

f_o = oscillator frequency $(f_s - f_i)$

Δf = r-f bandwidth = $2(f_s - f')$

f' = 1/2 power response frequency

$$\frac{\frac{1}{2}\Delta f}{f_s} = \frac{1}{2Q}$$

$$Q = \frac{f_s}{f}$$

(1) $$\alpha_v = \frac{\text{Relative Voltage Response at } f_o}{\text{Relative Voltage Response at } f_s} = \frac{1}{Q\,\frac{f_s}{f_o}\left[1 - \frac{1}{\left(\frac{f_s}{f_o}\right)^2}\right]}$$

Substituting $f_s = (f_i + f_o)$ into (1)

(2) $$\alpha_v = \frac{\Delta f}{\frac{f_i^2}{f_o} + 2f_i}$$

When f_i is in order of 50 Mc $\quad \frac{f_i^2}{f_o} \ll 2f_i$

thus equation (2) may be simplified as follows:

(3) $$\alpha_v = \frac{\Delta f}{2f_i}$$

Maximum error in equation (3) throughout the entire u-h-f television band when f_i = 210 Mc would be 36%

For oscillator power radiated,

(4)

$$\alpha_p = \frac{\text{Relative power response at fo}}{\text{Relative power response at fs}} = \left(\frac{\Delta f}{2f_i}\right)^2$$

APPENDIX C

GAIN AND NOISE FACTOR EQUATIONS FOR GROUNDED GRID AMPLIFIER

$$G = 2G_K = \frac{2(\mu+1)N_1N_2}{1+\frac{R_1N_1^2}{R_t}+\frac{R_pN_2^2}{R_2}+\frac{R_1R_pN_1^2N_2^2}{R_2R_t}M^2} \qquad (1)$$

where $M^2 = 1 + (\mu+1)\frac{R_t}{R_p}$

G_K given by Dishal p. 279 I.R.E., May 1944 for matched input impedance.

$$N_1^2R_1 = Z_{in} = \left[\frac{R_p+\frac{R_2}{N_2^2}}{M^2R_p+R_2/N_2^2}\right]R_t \qquad (2)$$

subst. the resulting value of N_1 in (1) and letting $R_2 = R_1 = R$.

$$G = \frac{(\mu+1)\sqrt{R/N_2^2}}{\sqrt{(R_p+R/N_2^2)\left[\mu+1+(R_p+R/N_2^2)/R_t\right]}} \qquad (3)$$

If $R/N_2^2 = R_L$

$$G = \frac{(\mu+1)}{\sqrt{\frac{R_p+R_L}{R_L}\left[\mu+1+\frac{R_p+R_L}{R_t}\right]}} \qquad (4)$$

5876 pencil tube	416A
$R_p = 8600$	$R_p = 6000$
$u = 56$	$u = 300$
$g_m = 6500$ umhos	$g_m = 50{,}000$ umhos
$C_{gp} = 1.4$ uuf	$C_{gp} = 1.25$ uuf

For a single tuned output circuit with a given bandwidth the resistance R_L must be chosen such that

$$R_L' = \frac{R_LR_o}{R_o+R_L} \qquad (6)$$

where R_o = output impedance at the plate of the tube.

$$R_L' = \frac{1}{2\pi C_{gp}\Delta f}$$

$$R_o = \frac{R_p\left[R_t+M^2R_1N_1^2\right]}{R_t+N_1^2R_1}$$

For the matched input condition $R_1N_1^2 = Z_{in}$.

$$R_o = \frac{R_p \left[(1 + M^2)(R_p + R_L) + (u + 1) R_t\right]}{\left[2 (R_p + R_L) + (u + 1) R_t\right]} \tag{7}$$

With R_L^{1} determined for a given bandwidth Δf, equations (6) and (7) must be solved simultaneously for R_L. Given R_L, the constant bandwidth gain curves can then be calculated.

Maximum gain is given when input and output circuits are both matched.

This can be shown by setting $\frac{\partial G}{\partial N_1} = \frac{\partial G}{\partial N_2} = 0$

$$G_{max} = \frac{u + 1}{\sqrt{R_p/R_t} + \sqrt{u + 1 + R_p/R_t}} \tag{5}$$

The noise factor is given by

$$F = 1 + 5 \frac{R_1 N_1^2}{R_t} + \frac{(1 + R_1 N_1^2/R_t)^2}{R_1 N_1^2} \text{ Req.} \tag{8}$$

when no second stage noise is included.

For matched input impedance

$$R_1 N_1^2 = \frac{(R_p + R_L) R_t}{M^2 R_p + R_L}$$

$$R_1 N_1^2 = \frac{R_p + R_L}{u + 1 + \frac{R_p + R_L}{R_t}} \tag{9}$$

Req. for a triode is given by $\frac{2.5}{gm}$ for the 5876, Req. = 385 ohms, 416A,

Req. = 50 ohms.

The minimum noise factor with mismatched input impedance can be found by setting $\frac{\partial F}{\partial N_1} = 0$. The resulting input impedance is given by

$$N_1^2 R_1 = R_t \sqrt[2]{\frac{1}{1 + 5 R_t/Req.}} \tag{10}$$

[illegible]

[illegible]